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How enriching sensory awareness develops and affects well-being throughout childhood

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How enriching sensory awareness develops and affects well-being throughout childhood

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ABSTRACT

This review study is an attempt to map the existing theoretical and empirical literature about a possible core capacity for well-being: 'enriching sensory awareness'. The mapping will address the extent to which the literature informs the hypothesis that enriching sensory awareness is a core capacity for well-being. The review includes systematic searches in four electronic databases and a selection of studies based on pre-set criteria. The systematic searches were conducted with the search terms 'enriching sensory awareness' and 'sensory processing'. From the review of literature, authors found the use of the term 'sensory processing' to be in line with the current scientific literature. Studies considering environmental and sensory enrichment as enhancement tools applied to typically developing children gave promising leads for the optimization of learning tools and learning environments. This was especially the case when sensory processing was enriched by various means. Through the review of available studies, various gaps in the literature could be highlighted. 'Sensory processing' relates to the definition of enriching sensory awareness as a core capacity within the framework of the Learning for Well-Being Foundation. However, sensory processing can also be considered a building block underlying the other core capacities. The review did not produce any studies with direct links between sensory processing and well-being or spirituality. A recent term introduced to describe the proposed enriching sensory awareness core capacity is 'embodying'. In combination with an exploration into the existence and impact of eight other possible core capacities, this study can contribute to the understanding of core capacities possibly benefiting child well-being.

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1. INTRODUCTION

'Sensory awareness' is a broad notion related to the way humans perceive, distinguish and focus on the world through the senses. It is strongly associated with the scientific concept of 'sensory processing', which is the capacity of the nervous system to perceive, process and react to sensory information (Jorquera-Cabrera et al., 2017). The scientific literature on sensory processing is substantial and a comprehensive review of it would fall outside the scope of this work. This report focuses instead on the *enrichment* of sensory processing as a core capacity. Enrichment is understood both as the child's ability to broaden their own sensory capabilities and as the societal mechanisms to support and nurture sensory development during childhood and adolescence by various means and in various contexts, such as school and family environments. A more recently introduced Learning for Well-being (L4WB) term for the enriching sensory awareness core capacity is 'embodying'.

The purpose of this literature review is to map empirical and evidence-based theoretical knowledge of the enrichment of children's sensory awareness and how it interacts with overall child well-being, throughout childhood. The main objectives of this study are to determine (a) whether the literature on enriching sensory awareness approaches it as a core capacity, (b) how it relates to the child's well-being and overall quality of life, and (c) how it develops throughout childhood.

This review is in four parts. The first part gives an overview of the background and general context of the project. The second part details the methodology used for the literature search and the selection of articles. The third part details the results of the literature review. The fourth part discusses these results in terms of streams of literature found, nature and quality of the data, relationships between this capacity and child's well-being, and its development throughout childhood.

2. CONCEPTUAL UNDERPINNINGS

This scoping review is part of an effort to map the scientific knowledge and empirical evidence about children's core capacities and their development. The theoretical framework of the L4WB approach conceptualizes children's core capacities and well-being as the ability to "realize one's unique potential through physical, emotional, mental, and spiritual development in relation to self, others, and the environment" (O'Toole, 2016, pp. 15–16). Further insight on the background of this paper is available in the Measuring What Matters overarching introduction and background paper.

2.1. Sensory awareness, sensory processing and enriching sensory awareness

According to the L4WB framework, enriching sensory awareness is the capacity to nurture, stimulate, and expand the capabilities of the senses (O'Toole, 2016). The core capacity is further explained as follows:

> Our physical senses provide the raw material/the content for our experiences of the world including the images with which we think, feel, and act. To be fully alive, our senses must be engaged and enlivened. This implies nurturing – proper care and healing – but also attending to our senses so that we expand and enhance their capabilities: learning to see, hear, taste, smell, touch with ever-finer distinctions. Our relation to our senses seems so fundamental that we might not even consider the need to give them additional

> attention; yet, there is widespread evidence that there has been significant decline in sensory abilities, particularly in children. Researchers have suggested this has resulted from overstimulation, neglect of proper care, and even the amount of time that we spend in virtual worlds, or isolated from our natural surroundings (Learning for Well-Being Foundation, 2019, pp. 2–3).

A first assessment of the literature revealed that the wording 'sensory awareness' did not emerge in the recent evidence-based studies included in this review. Therefore, 'sensory processing', which best reflects terminology found in the reviewed literature, is used instead. 'Sensory processing' generally refers to the handling of external (from the environment) and internal (from the body) information by the receptor organs and the peripheral and central nervous system. The construct can be divided into three stages: sensory registration (i.e., the discrimination, identification and interpretation of a sensory stimulus), sensory integration (i.e., the assimilation of various sensory information for movement coordination, for example), and sensory modulation (i.e., the regulation of the intensity of a response to the stimulus; Bröring et al., 2017). Functional sensory processing allows individuals to respond efficiently to their environment (Jorquera-Cabrera et al., 2017). Moreover, sensory processing abilities may have a substantial impact on many other aspects of a child's development because sensory information is at the root of other more complex cognitive, emotional and motor functions. There is scientific consensus on the existence of more than five senses, although their exact number is still debated (depending on what is considered to constitute a sense). At least two main other sensory dimensions are generally added to the five traditionally recognized senses (related to the five sensory macroscopic organs). These seven senses are: vision (sight), audition (hearing), somatosensation (touch), gustation (taste), olfaction (smell), proprioception (i.e., the perception of the movements through muscle contraction and position in space of the limbs, fingers, and other parts of the body), and the vestibular sense (i.e., the perception of the spatial orientation of the head and whole-body equilibrium; Wan Yunus et al., 2015).

The conceptual underpinning of the 'core capacity' is based on the L4WB theoretical framework. The most recent term used by L4WB to describe this core capacity is 'embodying'.

2.2. Four perspectives, spirituality and enriching sensory awareness

In this study, the literature on enriching sensory awareness was reviewed and organized according to the research streams resulting from a search conducted with multiple keywords and strict inclusion criteria. The relationship between enriching sensory awareness and well-being was explored holistically, by looking at the evidence-based literature on the mental (or cognitive), emotional, physical (or motor) and spiritual aspects of development.

The Matrix of Four Perspectives below is applied to the studies identified in this mapping paper in order to apply these four perspectives to the literature. Each of the studies in this review is positioned within the matrix and compared as a full body of evidence in the results section. For the application of the matrix, the L4WB definitions of the perspectives and capacity were followed (*see Table 1*). Applying the matrix to the literature identified will contribute to understanding the extent to which the literature allows for the theoretical classification of enriching sensory awareness within the L4WB's four perspectives.

Table 1: Matrix of Four Perspectives on enriching sensory awareness

			SPIRITUAL (S)
	content **'what'**	***process*** **'how'**	***intention*** **'why'**
MENTAL (M)	A *mental perspective* refers to "our cognitive and rational processes" and the functions of "envisioning, planning and valuing" (O'Toole, 2016, p. 17).	"A *mental* expression of enriching sensory awareness might be associated with the singularity and sense of boundaries of how we experience our bodies. It also relates to the quieting of our mind in relation to our sensory input" (Learning for Well-Being, 2019, p. 3).	"At a *spiritual* level, enriching sensory awareness can be expressed through stillness – as the silence and quiet that occurs when our senses are aligned with the universal forces" (Learning for Well-Being, 2019, p. 3).
EMOTIONAL (E)	An *emotional perspective* refers both to "our intrapersonal functions – our inner feelings, motivations and our interpersonal functioning – [and] our interactions with others" (O'Toole, 2016, p. 17).	"An *emotional* expression of enriching sensory awareness can be associated with tracking our emotional states and flows as they register in our senses. It relates to locating our emotions within our body" (Learning for Well-Being, 2019, p. 3).	
PHYSICAL (P)	A *physical perspective* refers to "the physical senses, to our bodies, and to the material and natural environments" (O'Toole, 2016, p. 17).	"A *physical expression* of enriching sensory awareness is associated with refining our senses and using the body signals as feedback" (Learning for Well-Being, 2019, p. 3).	

3. METHOD

To map the existing scientific literature on enriching sensory awareness, we reviewed the available literature using a scoping approach based on current best practice recommendations for the conduct of scoping reviews (Colquhoun, 2016; Munn et al., 2018) and on the PRISMA extension for scoping reviews protocol (Tricco et al., 2018).

The identification of potentially relevant literature for the review included several phases. A systematic search of published references was conducted using four electronic databases: EBSCO, ERIC (Education Resources Information Centre), Google Scholar, and PubMed. Reference lists from identified articles and recent literature reviews were then hand-searched to ensure that a comprehensive list of relevant articles was considered for inclusion. After selecting a list of keywords through consultation of a board of experts, a set of four search strings was created by using Boolean logic. Two search strings included one element related to the capacity itself, one element related to the population and one element related to the research question. The two others were identical without the element related to the research question, in order to ensure that no streams of literature were left aside. The

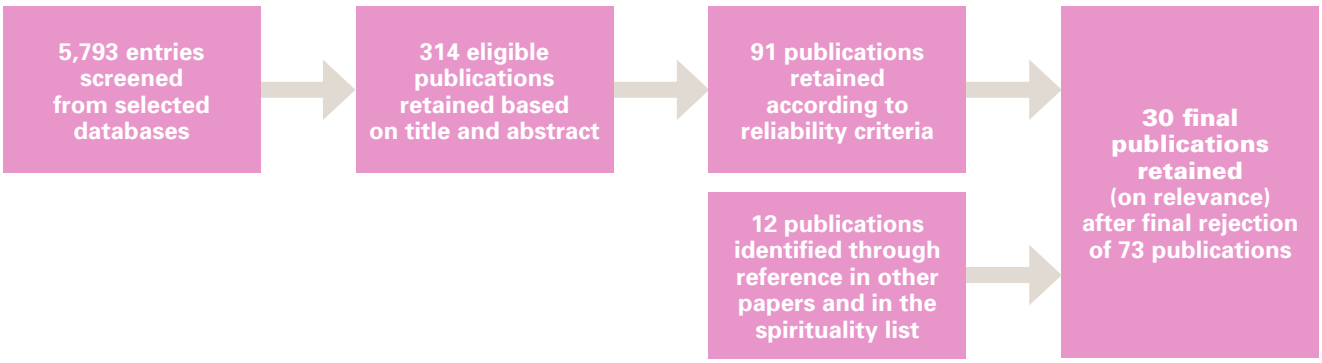
generated strings were: *sensory AND (awareness OR stimulation OR expansion OR integration) AND (Child* OR Adolescen* OR development) AND (capacity OR Well-Being OR Education)*; *Sensory enrich* AND (Child* OR Adolescen* OR development) AND (capacity OR Well-Being OR Education)*; *sensory AND (awareness OR stimulation OR expansion OR integration) AND (Child* OR Adolescen* OR development)*; *Sensory enrich* AND (Child* OR Adolescen* OR development)*. Because the searches were carried out before the term 'embodying' was introduced by L4WB, the searches did not explicitly include the term *embodying.*

The strings were adapted to each database's set of symbols of Fuzzy logic and elements of Boolean logic. For each search string, three consecutive searches were conducted in each database: a first search limited to review/meta-analyses (when the option was available; when it was not, the words 'review' and 'meta-analysis' were added at the end of the search string), a second search limited to the publications in the previous 5 years (2014–2019), and finally a third search limited to the publications in the previous 20 years (1999–2019). The chosen time frame allowed for an up-to-date overview of the most recent empirical findings and theoretical perspectives in this area of research. Because the searches resulted in a vast number of entries, they were sorted based on 'relevance' (i.e., studies with relevant wording and content appeared first) and the 200 first entries were screened for inclusion.

The screening process included two stages. Several eligibility criteria were used in the first screening stage based on title and abstract: (a) only English peer-reviewed publications were taken into consideration; (b) the study included research on enriching sensory awareness; (c) the study focused on child or adolescent populations, or on an adult population directly linked to children, such as teachers, educators or parents.

The reliability of the retained publications was then assessed in a second stage based on three criteria: (a) the study was conceptually coherent; (b) the study used an appropriate methodological approach; (c) the study was scientifically valid (see Appendix A for a description of these criteria). Only publications meeting all the criteria were included in the review. Information about the searches (including database, search terms, dates of search, number of search results, number of abstracts reviewed, and number of papers selected for screening) were archived in an Excel file and summarized in a flowchart (*see Figure 1*). Details of studies screened, and reasons for acceptation or rejection were also recorded.

Figure 1: Flowchart of the article selection process



We underline the fact that the literature cited and discussed in this scoping review is not exhaustive. The studies detailed in the results are representative of the large body of research in the field of sensory awareness and sensory processing enrichment from a developmental perspective. When a substantial number of studies on one specific topic met the selection criteria, only the most relevant were selected, to give a comprehensive understanding of the stream of literature. When available, meta-analyses and systematic literature reviews were preferred for review.

3.1. Enriching sensory awareness from the perspective of spirituality

Responding to the gap in evidence for sensory awareness from the perspective of spirituality, an additional search round was conducted to incorporate possible evidence from the spiritual perspective on enriching sensory awareness. In order to identify high-quality evidence relating to spirituality and sensory awareness the input of various experts was considered, including the Learning for Well-Being Foundation, the Fetzer Institute and relevant individual researchers focusing on spirituality. Additional searches were conducted to find alternatives for suggested articles that were not available.

The inclusion and exclusion criteria were applied to the resulting list of spirituality articles. This time, the suggested articles and books were only included when there was an explicit focus on spirituality, a relevant reference to enriching sensory awareness and an explicit focus on children or adults who work directly with children. Moreover, the same quality assurance inclusion criteria as in the general inquiry searches were applied (Appendix A). Finally, all publications had to have a standard format and not duplicate a study already included. After this process, no studies were encountered across the list of spirituality articles that mentioned enriching sensory awareness or sensory processing in a meaningful way for the objective of this review.

3.2. Applying the Matrix of Four Perspectives

Each of the studies included in the review was positioned within the Matrix of Four Perspectives to determine to what extent the L4WB hypothesis is supported with evidence. The matrix in Table 1 was applied to organize the articles in the various categories and levels (content, process or intention). In Table 2 descriptions of possible studies for the various categories are provided. This table was applied to categorize the included studies. The descriptions are based on L4WB publications (Table 1).

After the matrix was applied in the various mapping papers on capacities, two authors compared the application matrix, discussed the placement of articles which raised questions and made necessary adjustments. When agreement was not reached the authors checked the application of the matrix again and discussed the questioned papers until agreement was reached. Overall, 30 articles were placed in the matrix, and after review, the placement of 5 articles was adapted.

Table 2: Types of studies for the Matrix of Four Perspectives

			SPIRITUAL (S)
	content **'what'**	***process*** **'how'**	***intention*** **'why'**
MENTAL (M)	Studies on the presence of the capacity in children.	Studies that explore how the capacity develops throughout childhood/ in response to specific individual interventions.	Studies that focus upon why children perform/show the capacity and studies which focus on spirituality explicitly.
EMOTIONAL (E)	Studies on the relationship between the capacity and feelings/interpersonal relationships.	Studies on how relationships and/or feelings relate to the capacity.	
PHYSICAL (P)	Studies that focus upon the physical aspects of the capacity, or on doing the action.	Studies into how doing the action or the physical environment relate to the capacity.	

4. RESULTS

As mentioned, the term 'sensory awareness' did not emerge in the recent evidence-based studies included in this review. 'Sensory processing' best reflected the terminology found in the reviewed literature and was used for the database searches. 'Sensory processing' refers to the ability to register, integrate and modulate sensory inputs. The research on enriching sensory processing strongly relates to the conceptual framework of enriching sensory awareness described in the background section, since it focuses on the impacts of the child's environment on the development of the various senses (O'Toole, 2016).

From the database searches and the reliability analysis, 103 publications were retained. These publications on enriching sensory awareness throughout development were divided into two main streams of literature, both related to sensory processing. The first stream focused on the impact of an enriched environment (aiming at one or multiple sensory modalities) on the individual's development. The effect of enrichment programmes and interventions on sensory processing has been studied in the general population, but also as therapies for specific impairments. Studies examining these therapies and interventions were excluded due to the limited scope of this paper. Moreover, most of the theoretical framework of human sensory processing development and enrichment is based on data from animal models. Still, studies on animals had to be excluded from the review paper for failing to meet the inclusion criteria.

A second stream of literature approached sensory processing through its dysfunction in various childhood disorders. Research on atypical development and understimulation can inform developmental needs that cannot be explored otherwise, and the knowledge is likely valuable for understanding sensory awareness enrichment. Still, these studies had to be excluded from this review

because they failed to meet the inclusion criteria. Excluded studies fell within the following topics listed in random order: autism spectrum disorder (ASD); attention deficit/hyperactivity disorder (ADHD); traumatic brain injury; exposure to maltreatment and abuse; pre-term birth; institutionalization (due to state of orphanage or abandonment); intellectual disabilities; cerebral palsy (impaired muscle coordination); and early deprivation (visual, auditory, tactile).

Overall, from the 103 publications initially retained, the 30 most relevant studies were finally included in this paper.

4.1. Environmental and sensory enrichment

For clarity, 'environmental enrichment' and 'sensory enrichment' are distinguished in this section, although neither clear definitions nor a consensual distinction exist in the literature. Environmental enrichment refers to interventions implying multiple changes in an environment to increase an individual's sensory abilities. Sensory enrichment refers to more circumscribed interventions specifically targeting one sense. While environmental enrichment often implies consistent, long-lasting and multisensory ambient modifications, sensory enrichment generally consists of unisensory and intermittent interventions. Sensory processing enrichment is used as a catchall term referring to any kind of enrichment aimed at sensory processing.

The conceptual approach of the research on environmental and sensory enrichment is to stimulate the senses by various means and test whether this confers improvements in cognitive behaviour or any other skill. The effects of environmental enrichment are of interest because everyday experiences can potentially enhance or inhibit cognitive plasticity, and therefore the ability to learn. The idea of using an enriched environment for increasing cognitive ability and well-being has been developed since the 1940s (Hebb, 1947). In the 1960s, the discovery of sensitivity periods (or critical periods; Wiesel and Hubel, 1963) brought to light the importance of specific stimulations at particular periods in life for the healthy development of motor, cognitive and emotional abilities. This finding was accompanied by growing research on the potential of environmental and sensory enrichment (particularly in animal models which is not reviewed here).

In humans, even though schools, museums, theatres, books and other cultural and educational institutions and objects are means of enriching the individual's natural environment, scientific interest has recently resurfaced in research on the potential benefits of environmental and sensory enrichment. Environmental enrichment has been extensively studied in humans, notably in the classroom environment and digital media. Since many interventions in the academic context and involving digital media rely on visual information, most of the literature on vision is covered in this current section considering class environment (seven included studies) and digital media (three included studies).

Among the literature on environmental enrichment are studies exploring the effect of classroom environment on academic achievement, learning and well-being (Cheryan et al., 2014). Specifically, the quality of environmental factors, such as lighting, acoustics, temperature, air quality (and accessibility for disabled students – e.g., classroom organization adapted for hard-of-hearing students or students with physical disabilities) is correlated with academic achievement. For example, exposure to more natural light (i.e., daylight) compared to artificial light during teaching hours increased student performance (Tanner, 2008). According to the review by Cheryan et al. (2014), a limitation of such studies is that most use a correlational approach conducted in various schools and/or classes, without randomly assigning students to environmentally different settings. On the other hand, these results

corroborate laboratory studies linking suboptimal environmental conditions to a decrease in cognitive performance.

While certain studies show that individualization of the class environment can raise children's self-esteem (Barrett et al., 2015), others also point out the negative impacts of an excessive use of displays on attention and overall learning abilities. For example, Hanley et al. (2017) presented typically developing children (mean age 9 years) and children with autism spectrum disorder (ASD; mean age 10 years) in England with two kinds of videos of a teacher delivering classroom activities: one with a high level of classroom visual display, the other with none. Based on children's eye movements recorded during their watching and on worksheets completed afterwards, high levels of visual displays in the background lowered attention to the teacher and learning ability for all children. Attention was impacted to a greater extent for children with ASD but the attention of typically developing children was significantly impacted as well.

Similar results were found in the United States with two randomly assigned groups of six-year-old children placed for six introductory science lessons in a laboratory classroom either highly decorated or without wall decorations (Fisher et al., 2014). In the highly decorated classrooms, children were more distracted, spent less time on task and achieved smaller learning gains. Stern-Ellran and colleagues (2016) observed a greater number of behaviours indicating disruption in task execution in Israeli preschool children (aged 28 months) when they played on an overstimulating colourful surface area compared to a non-colourful, white one.

A large project in the United Kingdom sought to understand the impact of the physical characteristics of the classroom on academic progress. Based on the environmental–behaviour model, which posits that learning is modulated by naturalness, individualization and level of stimulation, several studies assessed the relationship between 10 environmental parameters (i.e., for naturalness – light, sound, temperature, air quality, links to nature; for individualization – ownership, flexibility, connection; for level of stimulation – complexity, colour) and academic achievement of 3,766 children (ranging from 5 to 11 years old) from 153 classes (e.g., Barrett et al., 2015; Barrett et al., 2017).Taken together, seven physical parameters (i.e., light, temperature, air quality, ownership, flexibility, complexity, and colour) accounted for 16 per cent of the variance in academic progression as measured by national curriculum level over the course of one year (Barrett et al., 2015). Interestingly, complexity of the classroom (i.e., the degree to which the classroom and the display provide appropriate visual diversity, as measured by the visual diversity of layout, ceiling and display) had a curvilinear effect on academic performance. Too little or too much complexity was predictive of poorer academic progress in reading, writing and mathematics, which suggests that an environment either visually too poor or too chaotic impacts the ability to learn. All in all, the literature tends to emphasize the importance of the classroom sensory environment on learning and academic achievement.

Today, a large proportion of the world's population is in daily contact with digital media at any age. Screen-based stimulations (such as television, computers and tablets) are becoming an integral part of children's play areas in many countries. Exploring the consequences of excessive internet use and internet gaming among children, adolescents and adults has become a rapidly emerging field of research, with strong clinical and public health implications (Christakis et al., 2018). Not only has excessive media usage been associated with behavioural addiction, but the extremely fast pacing of shows designed for young children (i.e., with rapid scene changes and quick edits) has led experts to hypothesize that this excessive auditory and visual stimulation might affect the developing brain.

Digital media are being used as an innovative educational tool for both typically developing children and those with developmental disorders, such as learning disabilities. Increasing research explores the benefits of multimedia electronic devices for educational purposes. It has been proposed that the effectiveness of digital tools for learning may be related to their integration of multiple sensory inputs. By exposing the child to multisensory stimulation (e.g., a tablet with text, voices, and animated pictures), multimedia platforms outperform their monomedia counterparts (e.g., a book with text and fixed images) in terms of learning and cognitive training. For example, in a study conducted in Israel on 136 kindergartners (aged five to seven) either typically developing or at risk for learning disabilities, Shamir and Shlafer (2011) demonstrated the effectiveness of an experimental multisensory e-book on emergent literacy compared to the classic scholar Israeli curriculum.

On the other hand, according to the 'overstimulation hypothesis' first tested in the 1970s, media overexposure during childhood may condition the cognitive system to expect an intensity of inputs that reality cannot provide, thus leading to attentional deficits in later life. Several studies linked internet gaming disorders to significant changes in cognitive abilities and in brain structure and activity, although they were correlational and did not establish direct causation (Christakis et al., 2018) . Interestingly, two US studies of preschool children younger than three years revealed not only that increased television viewing was correlated to an increase in the risk of subsequent attentional problems at school age, but also that this effect was modulated by the pacing of the watched shows, with fast-paced shows having stronger effects on future attentional abilities than slow-paced shows (Christakis, 2009) . Attentional capacity in early childhood is associated to future socioeconomic status, lower rates of substance use and incarceration (Christakis et al., 2018).

Several studies evaluated the effectiveness of enriching interventions aimed at specific senses beyond vision. The following sections focus on somatosensation (i.e., touch), gustation, audition, and motor/physical activities. Nothing has been found in children on olfaction, but because a large part of perceived taste is due to olfaction, the studies on taste preferences presented actually cover both senses.

4.1.1. Somatosensation

According to a relatively recent review (Field, 2010), touch is the least researched of the senses. Paradoxically, the skin is the largest and the first of the sense organs to develop. Skin-to-skin contacts, such as massage, have been proven to reduce developmental delays and increase growth and development in high-risk infants as well as to decrease depression in mothers giving the massages. Apart from massage studies and new haptics technologies designed to copy the sensation of being touched, whose impact has not been assessed scientifically, virtually no relevant literature exists on the enrichment of somatosensation in the healthy developing child population.

4.1.2. Gustation

Some research has explored ways to enrich gustation by improving food acceptance and increasing the willingness to taste novel food (i.e., diminish neophobia). Data suggest that only about two thirds of the inter-individual variation in food preference is genetically determined and that intra-individual variations are observed throughout life (Reverdy et al., 2008). External factors, such as food exposure or sensory and nutritional information, contribute strongly to neophobia (Reverdy et al., 2008).

According to a review by Harris and Coulthard (2016), scientific evidence tends to show that enhanced taste acceptance is based on a generalization effect: the more varied the experience of tastes during childhood, the better the acceptance of new tastes. Because of the transmission of taste compounds from the mother's diet to the infant through breastmilk, and because the taste of breastmilk fluctuates

according to changes in maternal diet, breastfeeding has also been associated with increased acceptance of taste variety later in life compared to infant formula milk. The review also points out the existence of early childhood sensitive periods for the introduction of complementary foods according to tastes and textures. They concluded that a combination of breastfeeding and timely introduction of complementary foods in the early years promotes future acceptance of new food, such as fruits and vegetables, due to a generalization effect.

A French study measured the effect of a 12-session sensory education programme aimed at reducing neophobia later in life in 180 children aged 8 to 10 years divided into a control and an experimental group. Although the sensory education programme had a positive effect on neophobia measured just after its completion compared to the control group, these effects disappeared after 10 months (Reverdy et al., 2008).

4.1.3. Audition

A large body of research has explored auditory enrichment, including musical training and bilingualism as effective forms of environmental/sensory enrichment. In the past decade, a recent line of research has investigated music perception and the musician's brain. This literature has outlined the positive effects of playing and learning to play a musical instrument on brain development in children and brain plasticity later on in life, particularly on the auditory and motor networks.

A growing body of scientific evidence reveals that musical practice transfers to language abilities and speech processing (François et al., 2015). In a longitudinal US study on high school students (mean age at pre-test 14 years), Tierney and Kraus (2013, cited in François et al., 2015) showed that musical training induces brain changes, allowing for a better distinction of speech sounds presented in a background noise. These improvements seem stable through life (Zendel and Alain, 2013, cited in François et al., 2015; Skoe and Kraus, 2012). Another longitudinal study revealed significant increases in speech segmentation skills (i.e., the ability to extract words from continuous speech, which is mandatory for language and new language acquisition) following musical training in eight-year-old French children (François et al., 2013, cited in François et al., 2015).

Another study on music instruction of eight-year-old children from under-served backgrounds at risk for learning and social difficulties in the United States indicated positive results on behavioural and neural consonant distinction after the second year of training (but not after the first; Kraus et al., 2014). In Australia, Williams et al. (2015) explored the impact of parent–child home music activities on various abilities and found a small but significant relationship between frequency of shared home music activities at ages 2 to 3 and vocabulary, numeracy, and social skills, and attentional and emotional regulation at ages 4 to 5.

Another wide field of research related to auditory enrichment is bilingualism. Both a bilingual environment and the fact of being bilingual are considered forms of sensory enrichment. Bilinguals' ability to speak and listen in two languages enriches their experience of the environment compared to monolinguals. Moreover, their active manipulation of linguistic complexity in order to manage and monitor each language and to prevent interference between the two works as an efficient training for auditory and executive systems (i.e., the cognitive control processes needed to undertake planned goal-directed behaviours). Therefore, bilingualism has a positive impact that encompasses enhancements in sound perception and more complex cognitive processes, such as attention and memory (Krizman et al., 2012) . Compared to monolinguals, bilinguals present enhanced frequency encoding abilities associated with pitch perception and executive function advantages.

Despite strong positive effects related to a second language acquisition, the literature points out differences related to the age of acquisition. Research comparing exposition to a second language from birth versus later in life reveals an optimal period for language acquisition during early infancy (although there may be several sensitive periods related to various aspects of language – e.g., phonology, syntax, semantics). Many studies also found a correlation between age of acquisition and definitive language proficiency (Berken et al., 2017).

Other studies investigated the relationship between socioeconomic status (SES) and bilingualism. In the United States, Krizman et al. (2016) reported that 14-year-old bilinguals of both low and high SES demonstrated more stable neural responses, stronger phonemic decoding skills, and heightened executive control relative to their monolingual peers. Another US study revealed an absence of difference in brain structure (cortical surface area) between mono- and bilingual adolescents (aged 12 to 20 years) from high SES families, but a significant increase in cortical surface area in bilingual adolescences from low SES families compared to SES-matched monolinguals (Brito and Noble, 2018).

A third stream of literature relates to phonological awareness (i.e., the ability to recognize and manipulate sounds in oral language), and in particular to the predictive character of phonological awareness on speech and literacy acquisition and development. However, since most of this literature did not approach the question of its enrichment, these studies were rejected (n = 4).

4.1.4. Motor/physical activities

At least two other main sensory dimensions are generally added to the five traditionally recognized senses (related to the five sensory macroscopic organs). These two senses are proprioception and the vestibular sense. Proprioception is the perception of the movements through muscle contraction and position in space of the limbs, fingers, and other parts of the body. The vestibular sense is the perception of the spatial orientation of the head and whole-body equilibrium (Wan Yunus et al., 2015). Especially these two senses make an exploration of studies on motor/physical activities relevant for this mapping on enriching sensory awareness.

The effects of physical activity on the brain have been approached through various neuroimaging techniques. Khan and Hillman (2014) concluded that physical activity is beneficial for cognitive and brain health in childhood, based on the review of research on children and adolescents linking physical activity and aerobic fitness to memory and executive functions, including inhibition (i.e., the ability to block irrelevant information or inappropriate automatic behaviours), flexibility (i.e., the ability to switch efficiently between tasks) and attention. The behavioural results are supported by neuroimaging data showing significant changes in volume and structure of brain networks associated with these cognitive functions. The review by Khan and Hillman (2014), however, emphasized the need for additional experimental studies to understand the relationship between physical activity and academic achievement and other daily activities. A meta-analysis of studies pertaining to physical activity and cognition in children similarly concluded a significant effect of physical activity on cognition during development (Sibley and Etnier, 2003).

Physical exercise and condition were also related to language skills in preadolescents and to global intelligence, logical scores and visuospatial scores in adolescents (Gomes da Silva and Arida, 2015). Interestingly, several studies suggested that maternal exercise during pregnancy positively affects foetal health and improves cognitive performance later in life (e.g., Gomes da Silva and Arida, 2015). Importantly, critical potential covariates (such as SES, workload of the mother or stress condition during pregnancy) were not always considered in this literature.

A randomized controlled study of 40 preschool children (aged 3 to 5 years) from extremely low SES families demonstrated that an eight-weeks creative dance intervention had a significant positive impact on social and behavioural competences (rated pre- and post-test by teachers and parents) in a United States population considered at risk for behavioural problems compared to an attention-control intervention (Lobo and Winsler, 2006).

Finally, a large survey exploring the relationship between sensory stimulation and physical and psychomotor development among 1,219 children aged less than three years in 26 communities in Pakistan found that the lower sensory stimulation recorded in rural homes was associated with decreased psychomotor development and underweight, even after controlling for undernutrition, SES and type of neighbourhood (Avan et al., 2014).

4.2. Sensory processing related to the child's well-being and to other core capacities

Sensory processing has been indirectly associated with the child's current and future well-being and quality of life through its impact on several skills essential for development. Sensory processing skills enable the child to engage with the world and interact adaptively with the environment (Dunn, 2007). They have been correlated to various cognitive functions fundamental for participation in daily activities and successful integration into society.

Strong relationships have also been found between sensory abilities and overall academic achievement. According to a scoping review (Dunn et al., 2016) , literature consistently associates school performance in reading (both with and without conditions) with auditory and visual processing. For example, a study by Boets et al. (2008) conducted in the Netherlands revealed that auditory and visual processing among preschool children aged 5 years were predictors of reading and spelling in first grade. Since visuospatial and visuomotor integration (i.e., the ability to process visual information to determine where objects are in space and the ability to coordinate visual information processing and motor control, respectively) are also related to academic achievement independent of IQ, socioeconomic status and sex, visual perception is probably a core feature of all academic programmes. Furthermore, differences in sensory perception (i.e., sensory processing impairments or sensory sensitivities) seem associated with challenging behaviours in normal children, as well as in children with ASD and those at risk of conduct behaviour (Dunn et al., 2016). We did not find literature directly exploring the relationships between enriching sensory awareness and other core capacities.

4.3. Enriching sensory awareness and its physical, emotional, mental and spiritual dimensions

The studies included in this paper were categorized by using the matrix of L4WB's four perspectives which shows that the vast majority of the studies fall within the physical category on the process level of the continuum (*see Table 3*). The literature on enriching sensory processing often included environmental input on the senses. Various studies examined cognitive process and were placed in the mental category following the L4WB framework. No study was identified that could be classified towards the immaterial end of the continuum.

The L4WB theoretical framework is built upon a broad interpretation of the mental, emotional and physical categories, which means that many studies fit the matrix when applying it. If other understandings of these categories had been applied fewer studies would have fitted the matrix. For instance, the emotional category is understood to include relationships beyond individual feelings,

and the physical category includes the material environment beyond the individual actions performed. If only studies including individual feelings or actions had been included, there would have been significantly fewer studies in the table, and it would show that these fields are less studied and empirically substantiated than it may seem. This would have especially affected the physical process category for this paper on enriching sensory awareness.

The literature included in this mapping review seems to suit different categories better, such as evidence-based literature on cognitive, emotional and motor aspects of development. Although the mapped literature on enriching sensory processing does not directly reference the four dimensions of development as proposed by the L4WB framework, sensory processing abilities seem strongly associated with the cognitive, emotional and motor aspects of development from birth to adulthood. Increase in sensory capacities following enrichment has been associated with improvements in executive functioning, attention, language abilities, and overall cognitive development (cognitive dimension), in motor control (motor dimension), social skills (cognitive and emotional dimensions), behavioural regulation (emotional and motor dimensions), and academic achievement.

Table 3: All studies in the Matrix of Four Perspectives

			SPIRITUAL (S)
	content **'what'**	***process*** **'how'**	***intention*** **'why'**
MENTAL (M)	1 study[1]	7 studies[2]	0 studies
EMOTIONAL (E)	0 studies	2 studies[3]	
PHYSICAL (P)	3 studies[4]	26 studies[5]	

Note. Not placed: 1 study.[6]

1 The one study placed at the Mental (M) content level is: Kraus et al., 2014.

2 The seven studies placed at the Mental (M) process level are: Berken et al., 2017; Boets et al., 2008; Brito & Noble, 2018; Dunn et al., 2016; Francois et al., 2013; Krizman et al., 2012; Tierney & Kraus, 2013.

3 The two studies placed at the Emotional (E) process level are: Skoe & Kraus, 2012; Williams et al., 2015.

4 The three studies placed at the Physical (P) content level are: Field, 2010; Harris & Coulthard, 2016; Reverdy et al., 2008.

5 The 26 studies placed at the Physical (P) process level are: Avan et al., 2014; Barrett et al., 2015; Barrett et al., 2017; Berken et al., 2017; Brito & Noble, 2018; Cheryan et al., 2014; Christakis, 2009; Christakis et al., 2018; Dunn et al., 2016; Fisher et al., 2014; Francois et al., 2013; François et al., 2015; Gomes da Silva & Arida, 2015; Hanley et al., 2017; Khan & Hillman, 2014; Krizman et al., 2012; Krizman et al., 2016; Lobo & Winsler, 2006; Reverdy et al., 2008; Shamir & Shlafer, 2011; Skoe & Kraus, 2012; Sibley & Etnier, 2003; Stern-Ellran et al., 2016; Tanner, 2008; Tierney & Kraus, 2013; Williams et al., 2015.

6 The one study not placed is: Dunn, 2007 (theoretical article).

5. DISCUSSION

The purpose of this review was to document the evidence-based knowledge of the enrichment of sensory awareness in relation to child well-being, and from a developmental perspective. This study provides insight into (a) enriching sensory awareness as a core capacity fundamental for child development, (b) the interactions between sensory awareness enrichment and child well-being and other core capacities, and (c) the age-sensitive development of sensory awareness enrichment. The L4WB approach recently adapted the term for 'enriching sensory awareness' to 'embodying'. This working paper still reveals relevant insights for the 'embodying' capacity due to the findings for sensory processing and enriching sensory awareness. It is a limitation that the paper did not include explicit searches into 'embodying'.

The search of the literature for the concept of 'sensory awareness' did not yield many evidence-based studies. On the other hand, research found extensive data and evidence-based literature on 'sensory processing' across childhood and its relationship to development and well-being. This may be due to the use and framing of concepts in domains that conduct applied research on child sensory awareness. Therefore, the authors recommend the use of the term 'sensory processing', which is more in line with the current scientific literature. The newly introduced term 'embodying' was not explicitly searched. Still, the findings and insights related to sensory processing can be helpful for the further conceptual development of the core capacity.

The review highlighted the stream of literature with studies considering environmental and sensory enrichments as enhancement tools applied to typically developing children. Substantial research has examined environmental and sensory enrichment. Studies on child development offer promising leads for the optimization of learning tools (through the use of digital media) and learning environments (through the control and organization of the classroom environment). They also reveal that the benefits of enriching sensory processing by various means (e.g., bilingualism, musical training, physical training) enhance the sensory systems involved. Executive functioning and other decisional abilities, behavioural control, social skills, and language abilities were also positively affected by enriching sensory processing by various means.

The research on enriching sensory processing relates strongly to the definition of enriching sensory awareness described as the capacity to nurture, stimulate, and expand the capabilities of our senses (O'Toole, 2016). Although the mapped literature on enriching sensory processing does not directly reference the four dimensions of development proposed by the L4WB framework (mental, emotional, physical and spiritual), sensory processing abilities seem strongly associated with the cognitive, emotional and motor aspects of development from birth to adulthood. This study did not find empirical evidence on the relationship between enriching sensory processing and the spiritual aspects of child development. Overall, the evidence does embed enriching sensory processing (and impoverished sensory processing) in the three other dimensions. In that sense, sensory processing partially fits the definition of a core capacity.

However, as a fundamental function necessary for interacting with the world, sensory processing can also be considered a building block underlying the development of most of the other core capacities. In that sense, it is more a property of the body than a core capacity. Furthermore, while we looked at the *enrichment* of sensory abilities both as an exogenous societal competency to nurture sensory development and as an endogenous child's ability to develop sensory capabilities, we did not find any literature directly exploring the latter. While other skills, such as active listening, inquiring, or relaxing,

can be taught or trained but ultimately rely on one's own willingness to engage in an endeavour, there is a lack of research exploring enriching sensory processing as an active process. In conclusion, we suggest that 'enriching sensory processing', despite being a primary competence necessary for the optimal development of the child, is situated at another functional level than the other core capacities. This conclusion cannot be drawn for 'enriching sensory awareness', since the wording 'sensory awareness' did not emerge in the recent evidence-based studies.

Regarding enriching sensory processing and well-being, although several publications show significant behavioural and brain changes in children associated with sensory processing improvement, a direct link between a specific training and an increase in well-being or quality of life remains difficult to uncover. Nevertheless, the modulatory effect of sensory processing on the cognitive, emotional and motor aspects of development and on various skills essential for child development and for everyday life highlights the importance of enriching sensory processing for child well-being. We note that while environmental enrichment can elicit positive developmental effects, excessive sensory stimulation can become disruptive and generate adverse effects, leading to reduced attentional and learning abilities.

A major gap in the literature concerns sensory processing enrichment. Many enrichment programmes and interventions (either uni- or multisensory-based) have been proposed and tested. Overall, research seems to show that the efficiency of the interventions depends on the age of the child, but that the optimal age may vary according to the sensory entry and the type of intervention. However, the literature lacks consistent, comparative, rigorous and large-scale studies of the effectiveness of enrichment programmes for children across their life course. These data are lacking in the context of childhood disorders and comparatively even more in the context of typical development. This caveat means it is not possible to draw conclusions on the existence or not of specific optimal ages for enriching interventions aiming at expanding sensory processing.

Moreover, most of the studies on sensory and environmental enrichment in the typically developing child population focus on childhood and early adolescence. There is a lack of reliable data on full adolescence (i.e., especially from 12 years old to adulthood). This reflects perhaps the current developmental models, mainly based on animal studies, on early deprivation cases in young children and on the knowledge of brain maturation, that suggest the existence of critical developmental periods for the sensory systems during early childhood (although they can vary depending on the sense).

Notably, most of the studies found in the literature on enriching sensory perception were conducted in the United States and Europe. While several studies concluded that there are no significant differences in terms of sensory processing across child populations of Israel, South Africa, Australia and the United States (Dunn et al., 2016), the lack of cultural diversity checks makes these comparisons less applicable across contexts. The developmental differences related to sociocultural contexts need to be addressed in future research. Typically, more studies should focus on populations beyond the United States and Europe to better understand whether this knowledge is transferable across cultures and societies.

Importantly, no sex effects were reported in any of the literature streams. We note however that a lack of justified hypotheses concerning sex effects in sensory enrichment is probably the reason why these effects were rarely tested.

We did not find studies revealing direct links between enriching sensory processing and other core capacities. But as an essential function for interacting with the environment, sensory processing is probably necessary for almost every other core capacity. Specifically, the capacities of listening, noticing (observing), relaxing, inquiring and empathizing are likely to be associated with sensory

awareness among children. Since enrichment of sensory processing has positive impacts on executive functioning (i.e., a composite set of skills involved in goal-directed thinking and decision-making), it may also relate to reflecting and discerning patterns. These associations, however, await confirmation and future empirical testing.

A limitation of this mapping paper is that various relevant streams of literature had to be excluded owing to the focus on studies considering environmental and sensory enrichments as enhancement tools applied to typically developing children. Excluded streams were: 1) studies exploring environmental and sensory enrichment and studies exploring sensory processing dysfunction in paediatric populations; 2) studies examining environmental and sensory enrichments designed as rehabilitating interventions for childhood disorders; 3) animal studies for more applied research that otherwise could not involve children due to ethics. This is an important limitation of this paper since the included studies only represent a limited group of typically developing children and leave many children unrepresented. Moreover, important insights from the animal literature are not described, while research on environmental enrichment in humans relies heavily on knowledge from animal models.

Finally, although there is consensus on the importance of early child exposure to a rich sensory environment, this assumption is primarily based on the knowledge we have of the sensitive periods of development, on data from animal models, and from impaired populations in humans. Future research needs to address the lack of data on (a) the effects of sensory enrichment at different stages of the child's development (a few studies on adults, not included in this review, examined the effect of sensory-based activities and their impact on risk of neurodegenerative diseases and overall cognitive decline), and (b) the characteristics that constitute an enriched environment.

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APPENDIX A: INCLUSION CRITERIA

	Criteria	Sub-categories	Description
1	What does it mean for a study to be **Conceptually Coherent**?	Introduction	Topic, purpose, and study rationale are clearly stated.
		Literature Review	The relevant conceptual underpinnings of the issue are fully explained.
		Research questions	Research questions and/or hypotheses are well defined and drawn from sound evidence-based theoretical or conceptual framework.
2	What does it mean for a study to use **Appropriate Methods**?	Methods	The research design and sampling are appropriate for the study. The study includes a well-articulated rationale.
		Theory (especially for studies with a primary theoretical framework)	A sound and established theoretical line is present.
		Data	Relevant data have been employed. Where survey data are used, the sample is well described and clearly appropriate for the task at hand.
		Analyses	The procedures and measures have been selected correctly and applied correctly.
3	What does it mean for a study to be **Scientifically Valid**?	Results	The results of the statistical/empirical tests are fully and correctly interpreted. Basic statistical information, such as probability stats, sample sizes, etc., and coherent explanation of findings are included – avoids overstating the study's importance and generalizability.
4	**Ethics (important but not a requirement to be accepted)**	Ethical review	If the research involves primary data collection and/or the use of sensitive secondary data, ethical considerations are described in the study. For example, the article might include details of the procedures followed to ensure the ethical review of data, an indication that the study received the proper oversight from review board or any mitigation strategies.

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