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Sensory-Based Toy Design for Children With Autism: A Research-Informed Approach to a Multisensory Engagement Cube

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ABSTRACT

This paper recommends user-centred design in developing multisensory learning aids that extend beyond mere entertainment to become sensory aids for children with Autism Spectrum Disorder (ASD) (Hijab et al., 2025; Unwin et al., 2024). User-centred design refers to a methodology where the end user is actively involved in the creation process to ensure the final product incorporates inputs from lived experiences and needs (Fabri and Satterfield, 2019). Children with autism may experience sensory differences such as hypersensitivity (sensory avoidance), hyposensitivity, (under-responsiveness) and sensory seeking with research indicating that over 80% of autistic children exhibit significant sensory processing challenges (Case-Smith et al., 2015; Ghazali et al., 2018). This review looks at research on sensory processing, sensory toys, and design engineering. The main finding of this literature is that sensory aids are most impactful when they accommodate the heterogeneity of the preferences of children with autism and provide the child with internal control over stimuli (Hijab et al., 2025; Unwin et al., 2024). Evidence shows that children with autism are more sensitive to light than any other sensory stimuli, making visual outputs a priority to prevent overstimulation (Habbak and Khodeir, 2022; Nair et al., 2022). Therefore, the design implication is that toys and learning aids need to be safe, predictable, calming, tactile and engaging. Engineering requirements may include rounded edges, non-toxic materials, and securely enclosed battery casings to ensure physical safety for children who may require additional safety considerations regarding risk awareness. (McAllister and Maguire, 2012; Tola et al., 2021).

INTRODUCTION

ASD is defined as a neurodevelopmental disorder. It is often characterised by restricted and repetitive patterns of behavior and social communication deficits. (Tseng et al., 2016, p. 1972)

Previous research has established that a large majority of children with Autism Spectrum Disorder (ASD), an estimate of 80%, tend to experience sensory processing challenges (Case-Smith et al., 2015) As per Case-Smith et al, these children display distinct patterns of hypersensitivity and hyposensitivity or sensory seeking behaviors while interacting with stimuli in their environment. (Case-Smith et al., 2015) Despite the widespread use of multisensory toys and environments, there is still an urgent lack of

guidelines to support the design and selection of these tools, which is why it is important to further analyze this area. (McAllister and Maguire, 2012)

Currently, the development of effective sensory aids is complicated by three primary challenges:

1. Sensory heterogeneity: Children diagnosed with ASD tend to respond differently to stimuli. Some are overwhelmed by movement or sound (hypersensitive), while others actively seek more intense forms of input to increase arousal (Unwin et al., 2024; Case-Smith et al., 2015).
2. Solitary Play Patterns: Children diagnosed with ASD often favor solitary or sensory-focused play, which can often be perceived as a lack of social interest and can potentially lead to isolation. (Hijab et al., 2025)
3. Ineffective Interventions: Commercial sensory-based learning aids tend to lack rigorous evidence and often fail to support the behavior of children on the spectrum. (Case-Smith et al., 2015).

Sensory heterogeneity is crucial because it directly influences a child's functional performance in their daily activities. (Case-Smith et al., 2015) The act of playing is not just a leisure activity in the context of children on the spectrum, but also a fundamental human right and a base for childhood development and friendship (Hijab et al., 2025; Kent et al., 2019). When sensory toys are not created based on evidence they can be a mismatch for the child's needs and potentially fail to provide the adequate stimuli to elicit adaptive responses. (Case-Smith et al., 2015).

A successful learning aid for children on the spectrum should be multifaceted in terms of its sensory output (Habbak and Khodeir, 2022). They should consider light, sound, texture, movement and safety (Habbak and Khodeir, 2022). Additionally, it should encourage independent play while supporting emotional regulation and also prevent potential overstimulation. Today, improved design guidelines are required because current practices tend to focus more on how to handle equipment rather than the sensory needs of children. (Unwin et al., 2024) By adopting appropriate design techniques, developers can identify the characteristics that make a toy truly engaging for a child and cater to their sensory requirements adequately. (Boyle et al., 2022; Nair et al., 2022).

Research Question: How can existing research inform the design of sensory-based toys for children with autism and the development of a multisensory engagement cube?

METHODOLOGY

This paper offers a literature review summarizing research on sensory processing, toy design, and interventions for children with Autism Spectrum Disorder (ASD). The literature search was performed in Google Scholar (primary source) and through the references of selected articles. Search terms were used including combinations such as "autism AND sensory processing," "autism AND toy design," "autism AND multisensory," "sensory-based interventions AND children," etc. Studies that were published between 2012 and 2026 and met the following criteria were included:

- Focused on children with ASD
- Dealt with sensory processing, design, interventions or engagement for autism
- Peer-reviewed
- Published in English
- Provided literature reviews or frameworks for evidence-based practice

Approximately 100-150 papers resulted from the first search. Further screening of the titles and abstracts helped to choose 15-20 articles that were subject to an in-depth analysis.

The selected articles were categorized according to the type of evidence:
Tier 1: Systematic reviews, large observational studies (for example, Case-Smith et al., 2015)
Tier 2: Observational studies, design studies, literature reviews (for example, Nair et al., 2022)
Tier 3: Frameworks, expert guidance, small-scale studies (for example, Hijab et al., 2025)

LIMITATIONS

This literature review is limited to English-language studies and was done by one researcher. Although Google Scholar searches across disciplines, not all literature might be covered by this database due to indexing of some journals exclusively in specialty databases.

LITERATURE REVIEW

Sensory Processing Differences in Autism

Research suggests that approximately 80% of children with ASD experience significant sensory processing challenges (Case-Smith et al., 2015). These challenges are generally categorised into hypersensitivity, hyposensitivity and sensory seeking (Case-Smith et al., 2015). Hypersensitivity, also defined as sensory avoidance, occurs when a child has a low neurological threshold. They tend to get easily overwhelmed or feel physical pain from sounds, lights, or textures that others find negligible (Ghazali et al., 2018). Conversely, hyposensitivity, also defined as under-responsiveness, involves a high threshold for sensory stimuli, where the child may seem indifferent to their surroundings or even fail to respond to social cues. Case-Smith et al., 2015; Nair et al., 2022).

Many children with ASD also engage in sensory seeking. This involves active, repetitive behaviors to help their nervous system reach a state of equilibrium(Unwin et al., 2024). Physical motions such as spinning or repetitive button pressing are examples of sensory seeking(Tseng et al., 2016). Receiving sensory input that is calming is crucial because it helps children maintain self-regulation and alertness, which in turn can reduce the likelihood of maladaptive behaviors like aggression or self harm (Habbak

and Khodeir, 2022; Case-Smith et al., 2015). Therefore, for toy design, these differences indicate that a "one size fits all" approach is ineffective. Tools like multisensory cubes must be carefully designed as per a child's sensory profile to provide engagement without causing distress (Unwin et al., 2024; Case-Smith et al., 2015).

Sensory Interventions and Self-Regulation

Sensory tools are used in therapeutic settings to support a child's emotional regulation. Sensory Integration Theory (SIT) and Sensory-Based Interventions (SBIs) are two common forms of intervention utilised to elicit adaptive responses from children with ASD. Case-Smith et al. (2015) characterise SIT as play-based and therapist-led to improve foundational neurological development in the long-term. Conversely, SBIs are immediate forms of intervention used for behavioral control, which include using weighted vests used to calm a child in the moment (Case-Smith et al., 2015).

Child-led interaction must be taken into account when designing toys for children with ASD because it provides the child with a sense of agency and internal control which can significantly reduce anxiety in unpredictable environments (Unwin et al., 2024; Nair et al., 2022). Calming input is typically repetitive and predictable whereas overstimulating input, such as flashing lights, can trigger distress (Tseng et al., 2016; Mostafa et al., 2024).

A multisensory cube should support self-regulation by allowing repetitive, predictable and child-controlled sensory engagement. Its elements can include buttons, switches and levers that can sharpen motor skills and allow repeated interaction (Hijab et al., 2025; Tseng et al., 2016).

Tactile Design and Texture

Tactile stimulation is one of the core components of sensory learning. The sense of touch helps children with autism reorganise sensory inputs and improve focus (Habbak and Khodeir, 2022; Nair et al., 2022). Textures help provide distinct sensory feedback. To exemplify, natural materials like wood are often perceived to be more calming than synthetic alternatives (Ghazali et al., 2018; Mostafa et al., 2024). Since autistic children have extremely diverse preferences, toys should include multiple textures and surfaces to cater to various needs(Hijab et al., 2025; Case-Smith et al., 2015).

Beneficial surfaces include smooth acrylic, ridged wood and soft fabric. Surfaces that provide gentle pressure or grip can also be particularly calming for sensory seekers (Hijab et al., 2025; Case-Smith et al., 2015). Bright shiny surfaces or strong textures should be avoided to prevent toys from becoming overwhelming (Nair et al., 2022; Ghazali et al., 2018).

While developing a multisensory cube for ASD, the cube should feature smooth surfaces like acrylic, some with wooden surfaces and some providing grip through elements like mechanical gears(Tseng et al., 2016). The toy should include different tactile surfaces, but each surface should be safe, durable, non-toxic, and not overwhelming to the touch (McAllister and Maguire, 2012).

Visual Stimulation and LEDs

Autistic children tend to be more sensitive to light than to any other design element(Nair et al., 2022). Visual stimuli like LEDs can be extremely engaging as they offer high-contrast feedback that captures attention, however they can become overstimulating if they are too bright, glare or flicker (Habbak and Khodeir, 2022; Nair et al., 2022).

To reduce this risk, the child must have control over the LEDs (Nair et al., 2022). Instead of random flashing, the light should respond directly to a child's action, such as pressing a button, and should create a predictable cause-and-effect loop (Hijab et al., 2025). This inclusion supports sustained focus and can encourage the child by proving they can control stimuli in their environment (Unwin et al., 2024; Nair et al., 2022).

Table 1: *Critical Comparison of Sensory Modalities in Autism Design*

Sensory Modality	**Prevalence / Findings**	**Citations**
Visual	~46.6% exhibit sensitivity in some localized surveys, though heavily split between severe hypersensitivity (distress from glare/flicker) and profound hyposensitivity (fascination with light/movement)	Nair et al. (2022); Habbak and Khodeir (2022); Case-Smith et al. (2015)
Auditory	~30–40% severe aversion to background noise, sudden echoes, and operational hums. • Highly correlated with elevated physiological distress and repetitive self-stimulatory behaviors	Mostafa et al. (2024); Habbak and Khodeir (2022)
Tactile	High variability; ~31.1% somewhat sensitive and 26.6% very sensitive to textures. Tactile feedback provides immediate, active self-regulation because it only stimulates upon physical touch	Unwin et al. (2024); Hijab et al. (2025); Tola et al. (2021)
Movement	Prevalent in sensory-seeking	Case-Smith et al. (2015); Hijab

	profiles where children actively seek intense somatic input (stimming)	et al. (2025); Tseng et al. (2016)

PLAY, INDEPENDENCE AND ENGAGEMENT

Independent play is a primary context for childhood development (Hijab et al., 2025). Many autistic children initially prefer solitary play as social interactions can be overwhelming or not in their interests (Tseng et al., 2016). A well-designed toy can act as a bridge and eventually facilitate collaborative play amongst children with autism (Hijab et al., 2025; Tseng et al., 2016).

Cause-and-effect play, where an action triggers an output, is particularly useful as well as it is intuitive and is not complicated by rules (Hijab et al., 2025; Tseng et al., 2016). Allowing children to explore their environment and toys without adult instruction, this kind of play supports their focus, engagement and independence (Unwin et al., 2024; Nair et al., 2022).

An object like a cube offers a handheld format which allows children to interact with it independently. Each face offers a different activity which can also give the child choice and autonomy (Hijab et al., 2025; Unwin et al., 2024).

Design Engineering Requirements

A multisensory cube must be durable to survive frequent use in therapy centers or classrooms. Its structure should be made of appropriate materials like wood and acrylic and it should be of a size that is big enough to be handheld (Ghazali et al., 2018; McAllister and Maguire, 2012).

Hygiene is essential, therefore all surfaces should be washable, wipeable or non-porous for easier disinfection (Ghazali et al., 2018). Safety is the primary engineering requirement: designs must include soft or rounded edges to prevent injury and enclosed battery sections that are only accessible with professional tools (Ghazali et al., 2018; McAllister and Maguire, 2012). To avoid choking hazards there must be no small detachable parts (Ghazali et al., 2018). Commercial development would also require compliance with toy safety standards such as ISO 8124 (general toy safety) and relevant regulatory requirements in target markets. Formal product-safety testing, materials certification, and durability assessment would be essential before consumer use.

Table 2: *Evidence-Based Sensory Features and Self-Regulatory Benefits of the Multisensory Cube*

Design Feature	**Physical Implementation**	**Benefit**	**Citation**
Active Tactile Interfaces	Buttons, toggles, or sliders that trigger localized light/sound *only* upon active touch, with no automated loops	Provides a sense of agency and acts as a mediator of sensory comfort. Ensures the child controls the duration and intensity of sensory shifts, reducing anxiety	Unwin et al. (2024); Hijab et al. (2025)
Color Coding	Restricting visible surfaces and soft LEDs to blue, green, and calming yellow/wood tones	Sustains attention and minimizes neurological fatigue. Captures visual focus and promotes positive behavioral responses without triggering the overstimulation associated with bright or flickering lights	Omar and Bidin (2015); Nair et al. (2022)
Non-Electronic Tactile Faces	Keeping at least one or two faces entirely passive, utilizing natural wood and soft textures	Captures and sustains focus. Acts as a strong positive visual motivator to keep the child engaged without triggering visual overstimulation or distress	Ghazali et al. (2018); Tola et al. (2021)
Symmetrical Layout	Organizing the cube with exactly one isolated, distinct sensory activity	Provides a sensory refuge. Allows highly sensitive	Mostafa et al. (2024); Tola et al. (2021)

	per face to eliminate visual clutter	children who are easily overwhelmed by lights/sounds a silent, low-demand texture surface to self-soothe	
Repetitive Mechanical Actions	Heavy-duty interlocking gears, friction sliders, or mechanical latches requiring manual force	Reduces cognitive complexity. Satisfies the child's preference for order, sequence, and predictable spatial structures, preventing neurological overstimulation	Hijab et al. (2025); Case-Smith et al. (2015)

Table 3: *Evidence-Based Design Framework for a Multisensory Cube*

Literature Finding	**Design Principle**	**Cube Feature**	**Citation**
Over 80% experience sensory challenges	Offer variety	Different textures and activities on each face of the cube	(Case-Smith et al., 2015)
Flickering/bright lights cause distress	Keep controlled	Child-controlled, dim LEDs	(Nair et al., 2022)
Repetition acts as self-regulation	Allow repeated actions	Buttons, switches and mechanical gears	(Hijab et al., 2025)
Children have diverse preferences	Make toy flexible	Modular and variable outputs	(Unwin et al., 2024)
ASD children may lack danger concept	Safe design and engineering	Rounded edges, enclosed electronics	(Tola et al., 2021)
Independent play supports agency	Support autonomy	Lightweight, handheld format	(Hijab et al., 2025)

DISCUSSION

The literature review confirms that sensory processing differences are a prevalent experience in children with autism, with over 80% of children exhibiting significant challenges in how they respond to environmental stimuli (Balasco et al., 2020; Hijab et al., 2025) These findings indicate that children with ASD require diverse types of sensory input depending on whether they display hypersensitivity, hyposensitivity or sensory seeking patterns. (Ghazali et al., 2018). Literature has evidenced that toys can support emotional regulation and social engagement if designed appropriately. (Kent et al., 2019; Hijab et al., 2025)

This review aims to translate complex autism and sensory processing research into practical toy design guidelines. It holds high importance amongst multiple stakeholders, and are crucial to each for the following:

- Parents: tools designed to provide a medium to manage extreme sensory needs at home, can make it easier for parents to engage their children and can also potentially reduce family stress by offering predictable and calming play options (Case-Smith et al., 2015; Nair et al., 2022).
- Teachers: Aids with the aforementioned design principles can facilitate classroom autonomy and allow students to self-regulate through independent play. In turn, this can minimize distractions and improve focus on academic tasks (McAllister and Maguire, 2012; Habbak and Khodeir, 2022).
- Occupational Therapists: These findings create an evidence-based criteria for selecting toys that provide suitable and specific sensory inputs required for therapeutic progress (Case-Smith et al., 2015).
- For Product Designers: This review highlights the necessity of moving beyond generic "fidget" toys toward inclusive, user-centred products that prioritize the voice and preferences of children with ASD (Unwin et al., 2024; Boyle et al., 2022).

The objective of this review was to understand how learning aids and toys for children with ASD should be designed to maximise their engagement and quality sensory learning. The findings directly support the proposed design of a multisensory engagement cube featuring multiple tactile surfaces, such as wood, acrylic, and fabric, and child-controlled LED interactions to provide predictable cause-and-effect loops (Habbak and Khodeir, 2022; Tseng et al., 2016).

RECOMMENDATIONS

- Stakeholder Involvement: Any designed sensory toys should be created with direct input from autistic children, their parents, teachers, and occupational therapists to ensure practicality and to maximise impact. (Unwin et al., 2024; Boyle et al., 2022).
- Aversion to Overstimulation: Designs should strictly avoid abrupt flashing, high-intensity noises, or sharp edges that can trigger distress (Habbak and Khodeir, 2022).

- Prioritize Child Control: Toys must allow children to control the sensory input, which acts as a mediator between sensory comfort and discomfort (Unwin et al., 2024; Hijab et al., 2025).
- Ecological Testing: Sensory toys should be tested in real settings, such as homes, classrooms, or therapy centers, to ensure its feasibility extends beyond a lab environment (Kent et al., 2019; Hijab et al., 2025).
- Customizable Modularity: Future versions of the cube should include replaceable or customisable sensory features to adapt to a child's specific sensory preferences (Hijab et al., 2025; Mostafa, 2024).
- Outcome Research: Further research should specifically test whether the cube effectively aids in calmness and sustained independent or collaborative play (Tseng et al., 2016; Mostafa, 2024).

FUTURE RESEARCH

This literature review presents research findings and translates them into specific design features which can be implemented in the proposed multisensory learning aid. To make its design more user-centred, the cube must be tested with actual users. The following stages could be carried out in order to validate these findings:

Stage 1: Prototype Development and Safety Testing
This stage would help create a functional prototype with customisable sensory features. Each element, such as buttons, switches and tactile surfaces, would have to be tested for safety compliance.

Stage 2: Usability and Sensory Comfort
A group of 8-12 children with ASD would be introduced to the cube to assess whether they can interact with it without overstimulation, measure their engagement duration and how easily they can use the cube independently. This would be done through observation and feedback from therapists and/or parents.

Stage 3: Ecological Testing
This stage would test the cube in a real-world setting like a classroom or home over a set period of time. Usage frequency, perceived behavior changes and sustained engagement with the cube could be measured and analysed.

Stage 4: Outcome Measurement
This stage would measure whether the cube displays the predicted benefits such as self-regulation and independent play in children with ASD. Methods of validating the above could include pre-test/post-test changes, and reported perceived behavioral changes from guardians and caretakers.

Stage 5: Iterative Refinement
This stage would incorporate feedback to refine the existing cube and repeat stages 2-4 with a new group of children.

LIMITATIONS OF CURRENT READ

Until this validation pathway is completed, the multisensory engagement cube remains a research-informed proposed design rather than a validated intervention. The literature review supports the individual design features but does not demonstrate that this specific cube improves outcomes for children with autism. Testing is essential before making claims about therapeutic effectiveness or recommending the cube for clinical or educational use.

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