textiles

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Review

Sensory Considerations for Emerging Textile Applications

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Abstract: Textiles are increasingly playing a role as a therapeutic medium in the disability field as well as in everyday life. This paper aims to review the literature on the relationship between textiles and sensory integration or sensory preferences in the general population. A brief literature review was conducted using PubMed (MEDLINE), SCOPUS, and Google Scholar. The review of the current literature highlights some key themes in the literature, including the indication that adaptive and sensory clothing design requires consideration of the textiles and fabrics being used, the functionality and appearance of garments, and affordability and access. The evidence suggests that clothing design should utilize soft fabrics which are seamless, have limited external tags, support social participation and functional engagement in daily activities, and are accessible.

Keywords: textiles; sensory integration; occupational therapy; sport; adult

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1. Introduction

People interpret the world around them through their senses. There are eight senses, which include tactile (touch), olfactory (smell), gustatory (taste), auditory (hearing), vision (sight), proprioception (knowing where your body is in space), vestibular (sense of balance and spatial orientation), and interoception (understanding and interpreting our internal processes) [1]. Individuals' sensory systems will develop over time as they experience a range of internal and external sensory inputs [1]. How their body interprets and processes these inputs is referred to as sensory integration [2,3]. As a result, every individual organizes their own thresholds and patterned responses to sensory stimuli [4,5]. At times, the interpretation and organization of sensory input can be interrupted or disrupted, which can have a profound impact on the way people participate in day-to-day life. Tactile sensory preferences and input can impact participation in self-care, interests, learning, productive and social environments, and activities [5].

Textiles and clothing play an integral role in how we interact within our environments to fulfill personal, cultural, and social roles [6,7]. They are a key part of people's everyday environment, continuously producing tactile and visual sensory inputs which trigger the body's sensory integration processes [1,2]. This can either lead to positive or negative experiences which will influence clothing or textile choice and preferences [5,8]. As a result, clothing can be particularly challenging for both children and adults who have sensory processing difficulties [9]. Clothing can be a tactile barrier or a facilitator to individuals being able to engage in daily activities that they need to do, want to do, or are expected to do [7]. When a person's ability to engage in meaningful daily activities is threatened due to sensory input, this can then have negative implications for their sense of wellbeing [9]. Therefore, it is important to understand the influence of sensory processing on people's interactions with clothing/textiles and the potential for clothing design to either enable or hinder participation in meaningful aspects of daily life.

People with atypical sensory processing patterns can be hyper- or hyposensitive to stimuli, including tactile stimuli elicited by wearing clothing made of particular textiles

or textures, e.g., wool, that are perceived by others as non-aversive [10]. Individuals will then respond to the sensory event, such as wearing a woolen blouse, based on their sensory threshold (which can be high or low), eliciting a behavioral response [5,10,11]. People may have difficulties processing the degree of intensity, duration, and frequency of sensory information [9,12]. Sensory integration interventions, which include textiles and clothing, can be provided to adjust and control the sensations and responses experienced by individuals when interacting with their environment [7,13]. Adapting the intensity or nature of sensory inputs can improve an individual's processing of sensory information and generated behavioral responses [7,13,14].

Textiles are increasingly playing a role as a therapeutic medium in the disability field as well as in everyday life [6]. There are several emerging applications of textiles, wearable garments, and clothing in health and disability contexts that demonstrate the use of textiles as a therapeutic intervention to enable participation in everyday life [6,15,16]. Integrating aspects of adaptive and therapeutic clothing into the design of mainstream textiles increases inclusivity and access for all [8]. For those who engage in the textile industry, providing an increased understanding of the implications of sensory processing difficulties experienced broadly by people can help to promote the advancing role and applications of textiles therapeutically [8,9]. This brief review aims to scope the current evidence behind clothing/tactile stimuli to determine how these can be either a barrier or an enabler for individuals with unique sensory processing patterns. This discussion will lead to a summary of sensory considerations for textiles applicable to all individuals and future applications of textiles and research. The aim of this rapid literature review is to scope the current evidence of the relationship between textiles and sensory integration or sensory preferences in the general population.

2. Materials and Methods

A rapid review of the literature published between January 2013 to October 2023 was performed between September 2023 and October 2023 according to the methodology of Ferrari [17]. The aim of this review was to seek out the current relevant literature, select literature suitable for the aims of the research, and summarize and report it. A rapid review style was selected to provide an overview of the current literature and allow for an exploration of future research directions.

2.1. Data Sources

The databases searched included PubMed (MEDLINE), SCOPUS, and Google Scholar. All articles were selected based on a title search, abstract screening, and full-article screening for relevance to sensory integration and textiles. Inclusion criteria included papers that explored the use of sensory integration approaches that consider a tactile component such as clothing, wearable devices, or e-textiles. Papers were excluded if they did not include tactile sensory input or focused predominately on the other areas of sensory integration or sensory modulation.

2.2. Search Terms

An initial search of the databases was conducted to determine reliable and suitable search terms that could be used to achieve the aims of the paper. The framework Population, Concept, and Context (PCC) was used to provide a clear search strategy amongst authors for all databases. The search terms were also identified using MESH terms. Search terms included "sensory integration", "tactile sensory integration", "sensory modulations", and "tactile sensory issues" AND "clothing", "textiles", and "garments" (see Table 1 for full list).

Table 1. Search terms in Population, Concept, and Context (PCC) framework.

PCC Element	Search Terms (Including MESH)
Population	"sport" OR "athlete" OR "disability" OR "general population"
Concept	"Sensory integration" OR "tactile sensory integration" OR "sensory modulation" OR "tactile sensory issues"
Context	"clothing" OR "textiles" OR "garments"

2.3. Selection Criteria and Strategy

Articles that were not available as a full text were not included in final analysis. Articles were included and identified based on their relevance to tactile stimuli issues with clothing. Independent searches were conducted by EK, JL, and TM. Any duplications were removed from the database search. All articles were initially screened by title and abstract before proceeding to full-text review. This allowed us to determine if the inclusion criteria were met before proceeding. All articles that met the inclusion criteria post full review and were agreed upon by the majority of the authors were included for full review. Discrepancies were reviewed by SPB for a secondary analysis of the data.

2.4. Data Analysis

Data were tabulated to demonstrate areas of application and key considerations for textiles and tactile sensory preferences. Key considerations included irritation of fabric (including discomfort of tags), the texture of materials, support for social participation, freedom of movement, durability, and affordability or access. Each key consideration could be applied to multiple populations, and examples of contexts have been provided.

3. Results

A total of 14 articles were identified as meeting the inclusion criteria and included. The results are summarized below.

Current Evidence for Characteristics of Tactile Sensory Considerations

The design of clothing can be a source of sensory discomfort and impact overall function. This discomfort can be attributed to several characteristics of the clothing, including the type of fabric and its texture, the presence or placement of seams and tags, and temperature adjustability [9]. There are several key tactile sensory considerations suggested throughout literature that may aid the design of sensory-friendly clothing. Central themes in the literature indicated adaptive and sensory clothing design requires consideration of the textiles and fabrics being used, the functionality and appearance of garments, and affordability and access.

Key findings in the literature highlighted that the texture, quality, and feel of the clothing during wear influence the wearers' comfort and sensory regulation [7,18,19]. This included a demonstrated preference for clothing which was seamless, avoided rough tags and labels, and considered the placement of inclusions or attachments, such as lights or buttons [9,12,19]. Shin, Smith, and Gaines [18] demonstrated that fabrics and fibers have the potential to either heighten or decrease sensory responses and to provide increased comfort or wearability of garments. When exposed to a range of fabrics, individuals tend to choose fabrics, garments, or pieces of clothing that are soft and comfortable [19]. Kyriacou, Forrester-Jones, and Triantafyllopoulou [7] also found that participants preferred fabrics such as satin, denim, and cotton due to these fabrics' softness, whereas fabrics such as polyester and wool were found to be uncomfortable and abrasive. Similar findings were reported by Wilfling, Havenith, Raccuglia, and Hodder [20], where cotton was preferred for its softness and wool was reported to be "scratchy". Comparatively, Zolyomi, Gotfrid, and Shinohara [19] reported a negative perception of noticeable bumps or roughness in the fabrics, which may deter consumers from purchasing clothing that is uncomfortable. The design of smart textiles for sporting or therapeutic markets can consider using smart

coatings, such as phase change materials, shape memory polymer, or conductive coatings to increase sensory comfort [21]. The tactile sensation of clothing is an important consideration not only for the consumer purchasing clothing but also for the groups manufacturing clothing to reduce waste and contributions to fast fashion.

The functionality of textiles was also identified as an important characteristic that was found to be closely linked to performance and participation in social, sporting, and community-based activities [9,12,20]. This included a demonstrated desire for clothing to be fashionable, ensure sensory and electronic features are inconspicuous, allow freedom of movement, and be compatible with the use of assistive technologies [9,20,22,23]. The comfort of clothing (such as electronic compression clothing) can significantly impact usability, particularly in social environments [22–24]. Usability may be a strong consideration for people commuting long distances on public transport, those working in outdoor environments, such as trades people, and people participating in sports who want freedom of movement. Many individuals avoid social or team-based activities that require uniforms, such as sports or scouts, etc., due to the sensory discomfort that is associated with the fit and freedom of movement [9,25]. Kyriacou, Forrester-Jones, and Triantafyllopoulou [7] found participants with autism spectrum disorder had more positive experiences with clothing that was flexible or easy to move in. Kabel, McBee-Black, and Dimka [9] found that existing clothing can be incompatible with frequent mobility aid use. For example, clothing can cause friction, slipping, or bunching of trousers for wheelchair users and restrict movement and mobility.

For rehabilitation or contexts requiring smart textiles for physiological monitoring or therapeutic sensory input, solutions which allow free movement and activity are required. This includes e-textiles utilized to monitor the gait, posture, positioning or movement, and sleep of an individual [15]. Duvall, Dunne, Schleif, and Holschuh [22] reported that existing wearable deep-touch-pressure products included obvious bulky attachments which produced unwanted noise or were difficult to don and doff; therefore, they chose to trial the use of shape memory alloy (SMA) as a deep-pressure wearable vest to address these issues. Garments also need to be breathable and easy to don and doff to avoid heighted sensory responses or discomfort [12,26]. In addition, Oatley, Choudhury, and Buckman [26] reported that smart textiles used to provide therapeutic sensory input also needed to be portable (i.e., use batteries, be comfortable for the wearer, and durable to accommodate movement, equipment, and laundering).

Few of the examined articles provided discussion relating to how the architecture of textiles might aid in achieving the characteristics mentioned above. However, the use of mesh knit fabric and stretch knit fabric were reported to support ease of movement, donning and doffing, and the breathability of compression and sporting garments [12,21,23]. In addition, Wilfling, Havenith, Raccuglia, and Hodder [20] highlighted that woven or knitted cotton and polyester blends are often used in sport garments to maximize comfort and durability.

Affordability and access create further limitations to developing textiles that would provide beneficial sensory intervention for individuals from a range of backgrounds and vulnerable populations. Sourcing and accessing adaptive clothing can be difficult either physically or online, and clothing often requires adjustments, resulting in increased time and/or cost [9]. Whilst online clothing purchasing has created a greater opportunity to access a range of textiles for the broader population, it has impacted the ability to feel the softness of the textile before trying it on. Some considerations that can be made to support people with specific tactile sensory needs include a description of the fabric (i.e., soft), stretch, and moveability [27]. Sizing issues/inconsistencies have been reported within the literature as a limitation to accessing adaptive or comfortable clothing [12,18]. Shin, Smith, and Gaines [18] identified that sizing information, such as a sizing chart, was often unavailable and inconsistent between companies and suppliers. Furthermore, the development of new textiles in this space must consider methods for mass production to

increase access and affordability [26]. Sensory considerations for emerging practice areas in healthcare are summarized in Table 2 (see Table 2).

Table 2. Tactile sensory considerations for emerging practice areas.

Tactile Sensory Considerations	Evidence and Application
Irritating fabric and textiles. Avoid seams and tags. Weighted clothing or bulky seams can cause discomfort. The fabric and location of the seams, tags, and labels.	Kabel, McBee-Black, and Dimka [9] found children with autism spectrum disorder can be highly sensitive to seams and rough materials. The presence of tags or bulky seams in compression or weighted clothing caused discomfort [12]. When interviewed, some adults with tactile sensory processing difficulties reported hypersensitivity and discomfort when wearing clothing with tags, labels, and seams. The location of these features may heighten discomfort [7].
Texture of materials: smooth or soft textures are often preferred.	Negative perception of noticeable bumps or roughness in the fabrics and a preference for soft fabrics [19]. Adults with autism spectrum disorder reported that soft clothing improved comfort [7]. Shin, Smith, and Gaines [18] suggest textiles can alert or calm, evoking a sensory response. The feel of clothing and fabrics was one of the three most important descriptors of comfort in sport clothing [20]. Wool was regarded as scratchy or uncomfortable, and cotton was described as soft and more comfortable [7,20]. Using soft textiles increases wearer comfort [25]. Smart coatings, such as phase change materials, shape memory polymer, or conductive coatings, can sense and respond to external stimuli, increasing the sensory comfort of sportswear [21].
Supports participation in functionality and design.	The comfort of clothing (such as electronic compression clothing) can significantly impact usability [22,24]. Consumers found functional/adaptable clothing to be unfashionable and limit participation [9,12]. A lack of social acceptability and comfort of clothing design can lead to avoidance of using it in public environments or on special occasions [9]. The physiological and thermoregulation properties of clothing influence sensation, comfort, and performance during sporting activities [20,22]. Creating textiles or sensory garments that are visually appealing and do not have the appearance of a medical device is important for usability [23].
Allows freedom of movement.	Smart textiles for physiological monitoring that allow freedom of movement [15]. Garments need to be breathable and easy to don/doff to avoid heighted sensory responses or discomfort [7,12]. Freedom of movement was the most important descriptor of comfort in sport garments [20]. Greater freedom of movement is associated with more positive sensory experiences and perceptions of clothing [25]. Smart textiles designed for therapeutic sensory stimulation were required to be easy to don (e.g., aprons, vests, lap blankets), able to be washed, and portable (i.e., battery-operated) [26].
Durable and long-lasting fabric: fabrics which are not easily damaged by friction from mobility equipment use.	Clothing can cause friction, slipping, or bunching of trousers for wheelchair users and restrict movement and mobility [9]. For higher-intensity activities, such as sports, protection and durability are key factors that influence the sensory perception of products [20].
Affordability and access.	Sourcing and accessing adaptive clothing can be difficult. There are a limited number of physical stores that sell adaptive clothing [9]. Accessibility has increased with online shopping; however, the clothing needs to be carefully described for the consumer so they are able to adequately determine if the garment meets their sensory needs [27]. Sizing issues/inconsistencies are a limitation to accessing adaptive clothing [12,18]. For e-textiles to be affordable and accessible, mass production is required [26].

4. Discussion

4.1. Clothing as a Barrier

Clothing can be a barrier or a facilitator to individuals being able to do the daily activities they need to do, want to do, or are expected to do [7]. A significant part of the general population, about 15%, have atypical sensory processing patterns [11]. The general population can be either more sensitive to sensory stimuli than most people or less sensitive to sensory stimuli than most people [1,5,7]. This can include some of the aspects discussed in Table 2, such as sensitivity to different types of fabrics. Sensory sensitivity is associated with physiological markers and implies differences in the detection of, and reaction to, sensory information, including information from the taste, touch, hearing, vision, and smell senses [4]. Clothing provides tactile stimuli to people, and the texture and materials of clothes can elicit maladaptive neurological and behavioral responses to individuals that can be very disabling, particularly in those individuals with atypical sensory processing patterns [16].

It can be challenging for everyone to find appropriate clothing for special occasions, such as formals/proms, etc., but it can be particularly difficult for people with sensory processing difficulties [9,12]. In a study by Kabel, McBee-Black, and Dimka [9], consumers found functional/adaptable clothing to be unfashionable and limit participation in social, education, and employment opportunities. Generally, individuals express a desire for sensory clothing, such as compression garments, to be fashionable and blend with their other clothing [12,23]. Furthermore, adaptive clothing that aids sensory integration can be difficult to source and expensive, and inconsistencies or a lack of information in sizing can limit consumers' access to appropriate sensory interventions [9,12,18]. Being able to touch, feel, and try on clothing significantly influences consumers' selection and decision to purchase items [20]. An inability to access clothing that matches an individual's sensory preferences can negatively affect self-esteem, body image, or their sense of identity and role fulfilment, etc., which can lead to a decline in physical and mental wellbeing [6,9]. A clear description of clothing, fabrics, seams, and make can provide a more accessible environment for people with sensory integration issues or sensory sensitivities.

4.2. Clothing as an Enabler

Despite the fact that clothing can cause problems for people with atypical sensory processing patterns, clothing can also be used as therapy for those with sensory processing difficulties [24]. As identified in the presented literature, soft clothing made from fabrics such as satin, denim, or cotton without bumps, seams, or tags can improve comfort and sensory regulation [7,9,18,19]. The use of shape memory alloy is being trialed in dynamic compression garments to produce products that are more comfortable, less bulky, and do not draw attention in social contexts [22,24]. Mesh knit and stretch knit fabrics were briefly mentioned in reference to compression and sporting garments for the purpose of increasing ease of movement, donning/doffing, and comfort [12,20,21]. Use of these inclusive design principles can increase the wearability and effectiveness of products which possess sensory processing benefits and applications [8].

Clothing and wearable garments, such as e-textiles, can support elite athletes in monitoring their progress and assisting with career progression [15]. The fabric and wearability of clothing have been considered important aspects of sports longitudinally and provide functionality to improve performance [15,25]. Some of the key areas in which textiles and fabrics should be carefully considered are cycling, swimming, team sports, and skiing [25]. The evidence presented demonstrates that that consideration of sensory properties in selecting textiles and design enables participation, performance, and intervention modalities for a broad spectrum of people who have individual sensory integration preferences [6,8,20].

5. Application of Tactile or Textile Integration Therapies

There are number of areas where tactile integration therapies could be applied to facilitate meaningful engagement in activity. Some of the key areas highlighted in the literature

are the use of sensory integration with children who have autism spectrum disorder [7]; those with tactile sensory preferences [9]; athletes who have tactile considerations which impact performance and an increased use of wearable devices [21,25]; and those with dementia [26]. These are just some examples of the existing and emerging applications, and further exploration and expansion are required in research and the global market.

5.1. Use of E-Textiles

E-textiles or smart textiles represent the integration of the traditional textile industry and technology, resulting in fabrics with electronic properties [15,19]. The application of smart textiles continues to develop within healthcare; however, their true potential within health, disability, and sensory assistive technologies is yet to be realized [15]. There are existing examples of smart textiles which help to decrease the arousal of the wearer via tactile stimulation that is activated and regulated by sensors integrated into the product [23]. Examples include the use of shape memory alloy (SMA) in the design of hugging and compression vests [22,24], garments that include vibration when activated, and compression garments that are activated by physiological indicators of anxiety, such as CalmWear [23]. Other smart textiles are being used to provide sensory input to increase interest and enjoyment and manage arousal levels [26]. Some designs have utilized lights, touch sensors, and sound effects woven into lap blankets and aprons to be used by aged care residents with a cognitive impairment or dementia diagnosis to provide stimulating activity [26].

5.2. Use of Textiles/Wearables to Support Sensory Integration for Adults in Sport

Comfort and sensory experiences associated with wearing sporting clothing are closely related to user performance [20]. Challenges with sensory processing are not solely associated with disability [5]. People who experience neurological injuries, such as a stroke or traumatic brain injury, may also encounter difficulties in processing sensory stimuli [28,29]. Mild traumatic brain injury (mTBI) and concussion continue to be of interest within sports medicine, particularly given the long-term impacts on athletes and their performance [30]. Sensory processing difficulties following mTBI can include hypo- or hypersensitivity to a range of sensory stimuli, such as changes in a person's processing of light, noise, smell, and tactile and movement stimuli [29,31,32]. At times, sensory sensitivity may heighten other symptoms, such as cognitive deficits, headaches, fatigue, stress or anxiety, etc., or vice versa [31]. Rehabilitation and therapeutic interventions focus on reducing and managing the impact of symptoms on an individual's function [29]. The findings of Scataglini, Moorhead, and Feletti [21] suggest smart textiles are being used more frequently in sports to monitor athletes and activity, with ongoing applications and improvements to further advance the field. Further investigation into the benefits and applications of smart textiles in sports rehabilitation, such as wearables that monitor and respond to physiological signals, may help to improve athletes' sensory regulation and recovery for improved performance following mTBI or to aid the performance of athletes through consideration of their sensory processing.

Wearable sensory interventions can be applicable to recovery post mTBI and may have particularly meaningful applications for those needing to return to high levels of physical activity and high-pressure environments, such as athletes [25,31]. Wearable devices/textiles can aid rehabilitation and general performance by providing sensory inputs to manage symptoms, or by monitoring sensory tolerance via physiological feedback throughout training [25]. These interventions can be particularly useful for the purposes of aiding sensory and emotional regulation by providing feedback to the parasympathetic nervous system to decrease heightened stress and arousal levels [23,31]. Wearable interventions can include compression garments, weighted vests, and biofeedback devices [23,24,32]. For example, Campbell and colleagues [32] utilized wearable sensors to provide audio biofeedback for improvement in vestibular and balance sensory processing post mTBI.

5.3. Tactile Integration in Mainstream Society

Affordable and access-friendly clothing that is readily available for all budgets and needs is difficult to source for individuals with tactile integration issues [9]. Online shopping has become more normative and allowed for access to international browsing; however, it removes the ability to touch/feel garments before purchasing [27]. For individuals with sensory integration issues, this is a barrier to finding clothing that meets their sensory preferences [9]. The consideration of using soft, comfortable, and breathable fabrics is becoming more common in areas such as sportwear to ensure performance is optimized for the wearer [15,21,25]. This consideration needs to become more common in designing clothing for the general population, with special consideration for people with neurodivergence, autism spectrum disorder, or tactile integration issues [8].

6. Conclusions

For clients of allied health practitioners and people living with sensory processing difficulties, this brief review has highlighted several key considerations for the design of clothing with therapeutic applications. The evidence suggests that clothing design should utilize soft fabrics which are seamless, have limited external tags, support social participation and functional engagement in daily activities, and be accessible. Aligning with these principles increases comfortability, functionality, and therapeutic benefits. Furthermore, the use of e-textiles and wearable technologies is an emerging area for allied health practitioners that shows potential to improve the therapeutic applications of clothing across a range of health and disability contexts. Given that sensory inputs can significantly impact a person's health and wellbeing, the diverse sensory needs of individuals should be considered when designing textiles either for the purpose of everyday use or to expand the availability of wearable textiles used in sensory integration therapies.

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