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A Review on Adaptive Sportswear

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ABSTRACT

Clothing for differently-abled has received its prominence recently, with various fashion brands focusing on inclusive design as one of their endeavors and researchers exploring the unmapped field. With growing awareness, one can feel the need for adaptive clothing specially designed for differently-abled users. Adaptive clothing for sports improves the physiological and psychological well-being of the player. Sports activities built physical strength and self-esteem of the differently-abled but there is limited review of literature on adaptive sportswear. Therefore, this paper presents a review of literature on adaptive sportswear. It reports a brief history on adaptive clothing, commercially available products designing parameters and design challenges in adaptive sportswear. To develop adaptive sportswear that is functional as well as fashionable, it should first suit the need and requirements of the users. User centric design approach can be adopted to do the research. The review paper also talks about integration of fashion and innovation in designing of adaptive sportswear.

Keywords: Adaptive Clothing, Differently-abled, Sportswear, Wheelchair users,

1. Introduction

Adaptive Clothing are specifically designed apparel for people with disability or special need who finds it difficult in dressing. Studies have shown that the functionality of a garment is the main cause of concern for wheelchair users (Feng and Hui, 2021). Clothing engineered and constructed for comfort and fit, can help the wearer to a certain extent, self-support the process of donning and doffing. It is a term used for Functional clothing for people with special needs and care. Special clothing that is designed for differently-abled bodies, the elderly, infants, etc. falls in this category of clothing. Adaptive Clothing is slowly getting its visibility in the market with popular as well as high-end designer brands like Asos, Target, Tommy Hilfiger, IZ Adaptive, Oscar de la Renta with care+wear showcasing fashion collections with specialized features. A differently-abled customer can benefit by using adaptive clothing that satisfies their specific need (Gleb et al., 2017). It goes back to the early 20th century US, where functional clothing was included in a rehabilitation plan for war veterans. This kind of effort can boost one's self-esteem to live in a society with dignity. However, in India, the brands catering to differently-abled are very limited. The main objective of this paper is to review the research work carried out in the field of adaptive clothing. This review paper discusses the importance of Adaptive Clothing and the functionality aspect matching the user needs.

Mind map shown in Fig. 1, is to visualize all facts and information through illustrations showing a general outline of adaptive clothing with special emphasis on sportswear. Adaptive Sportswear is a sub-domain of adaptive clothing that combines the need of the sports and the special needs of the sportsman, designed using user-centric design research approach. Adaptive sportswear can enrich the psychological and physiological welfare of the person (Strokes & Black, 2012). Depending on the use of more functional muscles while playing a sport, the heat zones of the body can be more prominent, that as a result can help in designing adaptive sportswear (Bairagi&Bhuyan, 2021). Special features can be added and designed differently for differently-abled sportsman. The components related to sportswear are highlighted to portray a clear understanding. In the mind map presented in Fig 1, the design process needed is indicated further moving on to theoretical framework and user-centric design approach. Furthermore, the historical facts in relation to adaptive clothing were discussed, linking the Indian adaptive clothing market.

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Fig. 1- Mind map of Adaptive Clothing and Adaptive Sportswear

2. History of Adaptive Clothing

Professor Robert Bogdan, a pioneer in the field of disability research, in his Disability Collection, Yale University, mentioned it very distinctly that adaptive clothing existed even in 1885 with a picture of a person in a wheelchair wearing a suit that was modified to fit the wearer appropriately while seated. However, only the privileged class could afford adaptive garments at that period. Dr Howard A. Rusk from the Institute of Physical Medicine and Rehabilitation, New York, known as the father of rehabilitation medicine, encouraged, and helped disabled war veterans during World War II with various physical and mental therapies. It was very evident from his work that he tried to rehabilitate differently-abled people from various fields to lead a quality life in society. According to him, any kind of disabled person can readapt to their surrounding with therapies and vocational training. Dr Rusk in addition included functional clothing as part of the rehabilitation program. In the year 1960, designer, Helen Cookman from Clothing Research and Development Foundation Inc. had patented a functional trouser with zippers on both the sides of the side seam to help to clothe oneself easily. This innovation done by Cookman was incorporated later by the brand Levi's Strauss and Co. in their ready-to-wear (RTW) denim trouser in 1975. Designer Florence Eiseman too partnered with Cookman to come up with A-line adaptive dresses for kids in 1963. First ready to wear fashionable kids wear available in the market that could even be adapted for differently-abled kids'. Inclusive designs that could be worn by everybody. It has been observed by Reich, that people can have various physical disabilities, but they would never like to see themselves be different from general people. Anne Kernaleguen in her book, "Clothing Designs for Handicapped" in 1978, had designed many patterns that could be sewed or altered at home. Designs that could be adapted to specific requirements of the person. In 1991, Lawrence, had explained how the body image and the self-esteem of a person are interrelated. Table 1 presents facts about researchers and designers working on Adaptive Clothing in 60s and 70s.

Table 1 - Historical facts about Adaptive Clothing

Term	Year	Source	Definition
Functional Trouser	1960	Helen Cookman	US Patent: Trouser for a handicapped person. Zippers on both side seam with stretchable denim fabric and a unique belt to hold the garment.
Functional Fashion	1961	Cookman & Zimmerman (Book)	Functional Fashion with simple solutions to modify ready-to-wear (RTW) clothes. Do it yourself (DIY) ideas
Functional Fashion	1963	Florence Eiseman with Helen Cookman (Clothing research and Development Foundation)	Designed A-line Adaptive dresses for kids. Fashionable and functional RTW clothes for everyone.
Clothing for handicapped child	1971	Gillian Forbes	Simple designs to help a differently-abled child to dress by themselves and enjoy while doing so.
Functional Levi's	1975	Levi's Straus and Co. in collaboration with Helen Cookman	Levi's Straus designed functional Levi's trousers for handicapped people.
Clothing for handicapped	1978	Kemalaguen	Alterations in regular clothing to be independent in donning and doffing. Aesthetically pleasing fashionable designs
Clothing for handicapped people	1979	Hoffman	Functional and aesthetically pleasing clothes for handicapped people

Clothing can play a significant role in supporting an individual to move around at ease. While designing clothes one should be aware of all the necessary facts related to the user's regular activities and movement patterns (Watkins 1984). Clothing manufactured for an abled body may not have considered the various aspects which are required for differently abled people (Gleb et al., 2017). For example, a differently abled person using a wheelchair will sit at all moments. Anthropometric measurements for a seated body vary with the posture being adopted in due course of time (Braganca et al., 2016). Helen Cookman had patented, 'Trousers for a handicapped person' in 1960. Her whole idea to design adaptive trousers was to make donning and doffing convenient for the user as well as caregivers. The trouser had side closures with zippers on the out seam running from the waist to the bottom hem. Cookman always used to analyze the movement of the body for which the garments were to be designed. Whether it was for dancing, jumping or wheelchair maneuvering. In the booklet, 'Functional fashions for the Physically Handicapped' by Cookman & Zimmerman (1961), useful solutions for physically handicapped people were introduced essentially in the context of rehabilitating people in the medical center. Some of the examples are presented in Fig. 2.

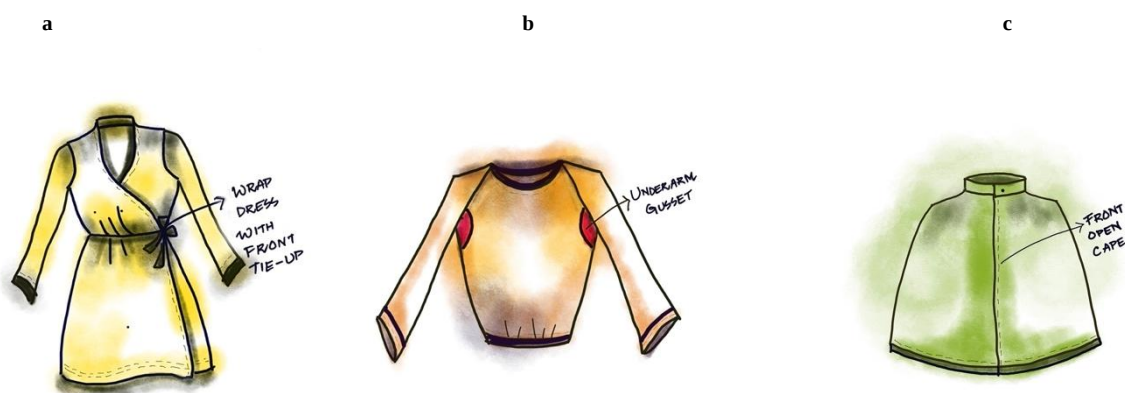


Fig. 2- (a) Open down the front dress; (b) Gusset underarm; (c) Cape for wheelchair users.

Open down the front dress shown in Fig. 2(a), is a kind of wrap dress that is fashionable even in this period. This specific design was meant to help patients who were paralyzed on one side and would find it extremely difficult to put the dress over the head. The inclusion of the gusset shown in Fig. 2 (b) could be worn by people who use crutches. It could give freedom to move and could get rid of strain from the underarm. It was very well mentioned that cape was extremely useful for wheelchair users rather than a structured coat Fig. 2 (c). This garment could be worn easily and could provide warmth to the upper body. Leinenweber Inc. started the first mail order customized suits for men in the US in 1964. Trousers patterns were cut high at the back than the front to fit the person in a seated position. Side pockets were made angular for better accessibility. Top blazers were cut away at the back for comfort and movement. In 1965, Florence Eiseman, an American designer designed a few adaptive kids' wear that can be worn by both able body and differently able body children. An A-line dress that can be unbuttoned in the shoulder line. It was shot in a film in collaboration with the National Society for crippled children, Clothing research development foundation inc. and Vocational Guidance and Rehabilitative Services (VGRS) Cleveland orthopedic company. As per designs developed by Chang et al. 2009, the appearance of the garments for differently abled persons should be as able-bodied garments. Comfort and aesthetic appeal should not be avoided while designing such garments. As a result, the researchers proposed a tri-dimensional adaptive clothing design considering the necessity for functionality and beautification. A design that can be worn outdoors without compromising fashion trends. This rider adaptive upper and lower parts of the garments can be separated by zippers.

In recent years, adaptive clothing has even progressed into the realm of high-end fashion. Lucy Jones, a Parson Design School graduate, inspired by Issey Miyake created avant-garde adaptive clothing for wheelchair users in 2015. Her 'Seated Design', received many accolades from the fashion fraternity as well as customers, incorporating functional, attractive, and comfortable designs. She understood the body fit and comfortability of differently abled customers depending on their body structures keeping the fashion quotient intact. Fit is something one should pay attention to and make design inclusive for all. IZ Adaptive a famous Canadian fashion brand concentrates on the aspects of comfort and easy to wear designs for wheelchair users. The trousers for wheelchair users have no back pockets or rivets to avoid the bulk. The material is stretchable for comfort. It also has double-ended side zippers for easy donning and doffing. Flat seams are used for skin integrity. Fasteners are also chosen with utmost care. Maura M. Horton, (US20140130233A1, 2012), patented multiple magnetic fastening assemblies for shirts and jackets. These patented magnetic fastening assemblies were even adopted by Tommy Hilfiger in 2017 in collaboration with Runway of Dream.

3. Commercially available Adaptive Clothing

Few notable Adaptive Clothing commercially available that caters to the specific segment in International and Indian market are put forwarded in Table 3 and Table 4.

Table 3- Adaptive Clothing in the International market

Year of establishment	Source	Information
1930	Silverts (US and Candian) www.silverts.com	Adaptive Clothing and footwear brand
1963	Designer Florence Eiseman designed for girls(kidswear). Adaptive A-line, easy to wear dresses that can be worn by everyone.	Fashionable easy to wear A-line garments for children(girls). Buttons in the shoulder joint.
1964	Leinenweber Inc. US,	First customized mail-order suits for men with wheelchair
1978	Buck and Buck www.buckandbuck.com	Adaptive Clothing brand
1990	Kratz and Soderback, Individual adaptation of clothes for impaired persons. A comparison of two groups with and without experience of adapted clothes.	Differently-abled person faces problems in finding appropriate clothing
1994	Eggleston, J.M., Bentrem, D.J., Bromberg, W.J., London, S.D., Biesecker, J.E., Edlich, R. F. Adaptive clothing for persons with mobility disorders after burn injury. J. Burn Care Rehabil.	Clothing developed for people who have suffered after burn injury
2009	IZ Adaptive, Canada (Izzy Camilleri) www.izadaptive.com	Designer adaptive clothing
2009	Koolway Sports, Canada www.koolwaysports.com	Outerwear for wheelchair users
2013	Reboundwear www.reboundwear.com	Adaptive post-surgery apparel
2014	US Patent Application Publication, Horton (Magna ready)	Magnetic fasteners for shirts and jackets
2014	Slick Clicks (HelyaMohammadian) https://slickchicksonline.com	Adaptive Innerwear (Patented adaptive innerwear design)
	Seven7 Adaptive https://seven7jeans.com/shop/adaptive	Adaptive jeans for men and women

2015	https://www.disabled-world.com/assistivedevices/adaptive-clothing.php	Clothes and footwear for differently-abled, elderly and people with restricted mobility
2017	Zappos Adaptive https://www.zappos.com/e/adaptive	Adaptive shoes and clothing
2017	Target kids adaptive, Cat and Jack https://www.target.com/c/kids-adaptive-clothing/-/N-11aue	Kidswear
2017	Heasley, 2017 https://www.disabilityscoop.com/2017/10/19/target-tommy-hilfiger-adaptive/24317/	Tommy Hilfiger and Target launched an adaptive clothing line
2017	Will and Well Singapore (Elisa Lim) https://willandwell.com	Clothing for wheelchair users
2017	Unhidden Clothing (Victoria Jenkin) https://unhiddenclothing.com	Adaptive clothing for people with tubes and colostomy bags
2017	Ffora, Lucy Jones, US https://liveffora.com/	Adaptive accessories
2018	MIGA Swimwear, US https://migaswimwear.com/	Adaptive Swimwear
2018	ASOS collaborates with Paralympian, Chloe Ball Hopkins https://www.vogue.co.uk/article/asos-chloe-ball-hopkins-jumpsuit	Waterproof detachable jumpsuit for wheelchair users
2018	Marks and Spencer, UK https://www.marksandspencer.com/l/kids/easy-dressing	Easy dressing range for differently-abled kids
2018	Oscar de la Renta along with Care+wear https://www.careandwear.com/collections/care-and-wear-x-oscar-de-la-renta	Adaptive hoodies
2019	Megami, UK https://megami.uk/	Post-mastectomy lingerie and swimwear
2020	Reset, London, UK (Monika and Usha Dugar) https://www.resetadaptive.com	Visual control of locomotion in Parkinson's disease
2020	Christina Stephens, Australia https://www.christinastephens.com.au/	Adaptive Clothing
2020	Intimately- Emma Butler, France www.intimately.co	Adaptive lingerie
2021	Uniteable- Brittany Burke, US https://uniteable.co	Adaptive Clothing

Table 4 - Adaptive Clothing in the market (Indian)

Brand	Category
Suvastra Designs, Chennai- Shalini Visakan (NIFT)	Men's and Women's wear
Move Ability Clothing (MAC), Kerala- Joe Ikareth	Men, women, kids wear
Aaraam se, Kochi- Ashima Bhan	Women's wear
Cocoon Senior Clothing by Old is Gold	Clothes for elderly
Renati- Parul Sachdeva	Clothes for visually impaired
Zyenika- Soumita Basu	Men, Women and Kids wear
Ezizio- Online store	Clothes for elderly
Nidhi Munim swimwear	Mastectomy swimwear
Cur8ability- Rainna Goel	Adaptive clothing
EKansh Trust, Pune- Anita Narayan Iyer	Adaptive clothing
NIMHANS, Bengaluru	Adaptive Clothing for patients
Orofit Bespoke, Mumbai- Dilip Jain	Bespoke custom-made men's wear

4. Designing of Adaptive Sportswear

4.1. Garment fit in sportswear

Fit for differently-abled wheelchair-bound players will vary with the type of physical disability the person has. It is not possible to generalize the fit of the garment with respect to the anthropometric data taken from a differently abled person. It is a complex procedure as advocated by Venkatraman and Tyler, 2016. As Watkins had explained that contour fit can be of three different types. a) Form fit, b) Action fit, c) Power fit. The fit of a garment highly depends on the stress and strain of the fabric materials used. Usually, the size of the stretched apparel is smaller than the body measurements. Body measurements can be taken with the help of Anthropometry. Anthropometry is a science to study the human body measurements like dimension, mass etc. (Gupta, 2014). This technique can be utilized to acquire body dimensions and as a result, better fit can be achieved. It is a combination of two Greek words, 'anthrop' meaning human and 'metrics' meaning measurements. This technique was first used by the military to make uniforms. Many researchers have studied on various aspects of taking measurements of the human body in standing as well as sitting positions. Both manual and 3D scanning methods are possible to take body measurements. Important aspects in relation to anthropometry of differently-abled sports people need to be studied. As in the case of wheelchair-bound players, it has been reported by Braganca et al. (2016) that:

- A wheelchair person can gain weight in the abdominal area
- The trunk of the person can shrink in size
- Height and weight of the person can change
- Hips may widen in due course of time
- Upper back bending will surge
- Angular position of the elbow varies
- Leg length changes due to the flexion of the knees

Better fitted sports garments are ergonomically engineered to enhance the performance of the sportsperson and the garments particularly help in proper blood flow in the body. The compression garments in present times are used extensively by both elite and recreational players. It provides support to the muscle thereby minimizing any further soft tissue injury as put forward by Venkatraman and Tyler (2016). It is seen that compression garments in addition reduce the pain of the affected area and can bind the tissues tightly and effectively. In compression therapy, such pressure garments are used for the lower limbs for regular venous blood flow. When human body parts are covered with stretched fabrics, compressive force is generated (Tyler 2016). As stated by Hayes, 2018, seams on compression garments should be engineered with apt geometry, type, and tension of the thread to be used, stitch density to refine the elastic recovery. During a rugby match, compression garments tapes are used that may aid the player to support the body posture and help in muscle recovery. Similar techniques can also be beneficial for wheelchair sports players. Quicksilver's Explosive Technology compression boardshorts are designed with ergonomic banding placed strategically around the lower torso.

Since 1980, 3D Body Scanning is gaining popularity exponentially in the apparel business which is one of the best mediums to take body measurement. This accurate and fast technology can be used to capture body measurements of any shape and size in a few seconds. Yu, 2004, had pointed out main advantages in using 3D body scanning are:

- Collection of non-contact body measurement data for sizing
- Various category mannequins for retail purposes
- To evaluate fit, drapability and aesthetic appearance

In 3D body scanning, there is laser technology, infrared technology, Photogrammetry, Moire Topography etc. 2D patterns are made in the CAD system, stitched digitally and then it is simulated in the 3D system to check the actual fit and drape of the garment. Various fabric types, colors, trims can be chosen from the library as per the design. During this Pandemic situation from 2020, designers are using 3D to showcase their new collection. Cyberware, Human Solutions, Telmat, Hamamatsu, Intellifit (Alvanon), TC2, Size Stream etc. are some of the technologies dealing with 3D body scanners.

4.2. Ergonomics

Ergonomics is a word derived from Greek words, '*Ergon*' meaning work/labour and '*Nomos*' meaning natural laws. Keeping the anthropometric aspects in mind, the clothes should be designed ergonomically in a way that is comfortable, can provide security and can ease the physical mobility of the user in various segments (Das Neves et al., 2015). In recent times there have been researches in the field of medicine and social sciences and as garment specialist, we need to pay attention to various disabilities which exist and restricts the free movement of the person. The clothing should be designed in a very advanced quality by incorporating the science of ergonomics to make it more functional (Elena et al, 2020)

4.3. Seams and Stitches

Broken seams/ stitches are the major problems in knitted apparel. Due to the amount of force put on to the seams when the fabric is stretched, the stitches crack open. To avoid such circumstances, a right type of thread should be used (Textured polyester/ textured nylon for sportswear). Choosing the correct stitch type can also prevent seam breakage. While constructing sportswear, Stitch Per Inch (SPI) should also be investigated for stitch strength and durability. When two or more plies are sewed with thread, it is called stitches. Various Stich types available that are used in the manufacture of sports garments are classified into the following classes (Glock and Kunj, 1995) as mentioned in ISO 4915:1991:

- **Class 400:** Multi thread chain stitch, one or more needle thread and one looper thread. Stitch type 401: Two thread chain stitch which is quite commonly used on T-shirts has a needle thread and a looper thread. The top view looks like a lock stitch and the bottom view has loop formation. This stitch is also found in judo/ karate suits because of its extensibility. Stitch type 406: This stitch consists of two-needle threads and one looper thread. Bottom cover stitch- durable and stretchable and are used in the manufacture of neckline and hemlines of T-shirts, leggings, belt loops etc. Considered a good stitch for covering the folded raw edges at the hemline.
- **Class 500:** Overlock, serge or overedge stitches. Stitch type: 504 is used in serging of single plies to finish the raw edges. It is one needle thread and two looper thread. E.g., Trousers inseam and out seam. Stitch type: Stitch Types: 512 and 514 (Four thread): Mock safety stitches with two needle and two looper threads. Used mostly in knitted garments to cover the raw edges inside seams and shoulder seams. 516, safety stitches are also used in sportswear which is basically the combination of 504 and 401.
- **Class 600:** Cover stitch/ Flat lock/ Flat seam. Stitch types: 605/607: Commonly used in sportswear nowadays for its extensibility and elasticity. Seams: According to Glock and Kunz, 1995, when two or more materials are joined together to give shape to a garment, it is known as seams.
- **Superimposed Seam:** One-ply placed on top of another ply and sewing process takes place. Most seen seam in a garment
- **Lapped Seam:** Lapped seam is a kind of a flat seam
- **Bound Seam:** Bound seam is a binding stitch. Mostly seen in sportswear. A separate strip is used to cover the raw edges. It can be neck binding, sleeve binding etc.

In present times, seamless technology is found in numerous categories of garments like sportswear, innerwear, compression garments, medical garments etc. (Brownbridge, 2016) The garments which are made with knitting 3D technology without seams are called Seamless Technology. These garments are comfortable, light weight, fits well and aesthetically appealing. In this seamless technology, manufacturers basically utilize polyamide microfibers for its durability, breathability, and fast drying properties. Studies says that flat seams are also favorable for sportswear as it can prevent soreness and can give a smooth and comfortable feel to the wearer. Seamless garments can be produced with the following knitting techniques: (a) Circular bed knitting and (b) Flatbed knitting. Machines manufacturing seamless garments available are Shima Seiki (Japan), Stoll (Germany), Santoni (Italy), Karl Meyer etc. Advantages of seamless technology can be mass production and less fabric wastage in the manufacturing process (Brownbridge, 2016). Stitch less technology is a process by which a garment is made without utilizing thread for sewing. Two techniques are involved in the process: (a) Bonding: Bonding with the support of adhesive & (b) Welding: High-frequency radiation with laser welding/ ultra-sonic welding This technology has been used extensively in present times in sportswear, innerwear, outerwear, and protective garments (Textile Outlook International, 2018). The process that seals the joints totally unlike the usual sewing process where it causes holes due to the passing of needle through the materials. Brands like Adidas, Nike, Lululemon, Under Armour, Patagonia, The North Face etc. employ this technology in their products. Stitch less technology besides can be noticed in automobiles, aerospace textiles, technical textiles home textiles and on many other advanced materials.

4.4. Body movement

Ashdown, 2011, had pointed out that a well-designed garment should not obstruct the movement of the human body. Understanding of the body movement is very pertinent at this stage. Kinesiology, an important branch studies the movement of a body. It can be applied to improve an individual's mobility, strength, and endurance. It can be used in rehabilitation therapy for individuals to enhance their physical wellbeing. Kinesiology is basically associated with Anatomy (Science of shape and structure of human body), Physiology (Study of living organisms) and Biomechanics (Study of forces interacting within living body) (Neumann, 2010). Advocated by Watkins and Dunne, 2016, there are three types of planes that divide the body, Sagittal (Left and right), Frontal (Front and Back) and Transverse (Top and Bottom) are shown. Some of the Kinesiology terms are as follows:

- Abduction: Movement of the part of the body away from the midline in the frontal plane.
- Adduction: Movement of the part of the body towards the midline in the frontal plane
- Flexion: Movement that takes place while bending in the sagittal plane.
- Extension: Opposite of flexion. A movement that takes place while returning to its original position in the sagittal plane.
- Rotation: Movement that takes place around an axis.
- Translation: Linear motion is known as translation. It can happen in rectilinear motion or curvilinear motion.

4.5. Physio-thermal regulation in Adaptive Sportswear

Wheelchair players are prone to diseases related to environmental challenges like hot or cold climates that can affect the thermoregulation of the body (Griggs et al. 2014). Very categorically it was mentioned that tetraplegic players with high lesions have sweat imbalance compared to paraplegic players. Moreover, literature also shows that the core temperature of differently abled body during physical activity rises more than compared to abled body (Webborn et al. 2005). Infrared thermal imaging (thermography) technique can be carried out as an experimental process on wheelchair players to check the changes in skin temperature during the match. This technique can give an insight into the skin temperature rise and how the player can adapt to the thermal transformation. This thermal imaging of the body, facilitates in designing sportswear, considering the zones of the body with high temperature while in action in a real setup. Creating designs that can complement those heat zones to perform better and remove exhaustion is very crucial. Infrared Thermography (IRT) can also provide useful information about the player's health and recovery pattern after various physical activities. Infrared thermography or thermal imaging is a non-contact, effortless and low-priced technique to map the body to test the body temperature variations. In this technique, infrared cameras produce thermal images with electromagnetic waves. In keeping with the views of Fernandez- Cuevas et al. (2015), there are basically three influence factors in IRT:

- Environmental factors
- Individual factors
- Technical factors

4.6. Aerodynamic considerations in designing of Sportswear

During high-intensity sports activities, aerodynamics plays a very crucial role in enhancing the performance of the athlete by reducing the aerodynamic drag and lift. The pressure contacts the athlete or his equipment and the air around him finally deciding whether the athlete can move faster or slower (Barelle, 2011). Aerodynamics experiments are done to reduce the wind drag and minimize the time taken for the sports activity. The same experiment can be performed on wheelchair tennis to study drag and investigate its effect on sportswear. The complex relationship between the flow of air, sportswear and body type of a differently-abled player, the type of sport, motion and physical attributes of the fabric like air/ water permeability, elasticity, surface structure, etc. studies can be executed. Pressure Drag: When the player is moving at a very high speed, the air hits the front of the player which as a result creates a force. Subsequently, the air is dragged along at the back portion of the player giving rise to a draft zone. Friction Drag: While the player is in motion, the air also glides across the surface thereby creating the friction drag. Though the proportion of the friction drag is smaller than the pressure drags, it is a quite significant phenomenon. According to Chowdhury (2012), an athlete's body position, wind speed, fabric properties, garment construction, etc. are very imperative to study aerodynamics. Most of the aerodynamic drag happens due to the shape of the body that gradually transforms into pressure drag. With respect to the fabric properties, the factors that affect are the surface roughness, seam placement, air permeability and fibre orientation. When it comes to garment construction, the seams, panels, closures, etc. can have a direct impact on the aerodynamic study. In Aerodynamics, Wind Tunnel Testing is one type of experiment that is carried out to examine the wind drag/ lifts to correlate fabric properties, surface textures and air permeability in a controlled environment (Chowdhury et.al., 2008). Aerodynamic drag and lift are directly dependent on these factors. Wind tunnel testing can be of the actual size or of scaled down-size to conduct the experiment. Reynolds number and drag coefficient can be calculated to get the result. Many simulated studies have been done in the past to get the desired results. The experiments were done by Brownlie in 1992 in a scale downsize in a controlled environment by using various fabric materials on a cylinder model. Some points to consider are as follows:

- To determine the mean velocity and environmental factors like- temperature, precipitation, and wind for the sport desired
- Need to measure the mean width of the fibre, surface roughness, fabric grain and vapour permeability of the material.
- Fabric seams should be flat type and should be placed away from the wind-facing areas.
- Garment should be custom fitted to the body of the model to reduce negative impact.

5. Design Challenges in Adaptive Clothing

Research papers reported on the literature mostly discuss the need of wheelchair users that highlighted the importance of functional needs, fabric performance, fit, safety, aesthetic, expressive needs, quality of life and extrinsic attributes (Feng and Hui, 2021). Functional needs top the list of all other requirements for developing adaptive clothing.

- According to Chang et al. (2009), the clothing for differently-abled should be designed keeping in mind the functionality and aesthetic aspects. It should match the body movement and assistive devices they hold in day-to-day activities. It should enrich the shape of the body and boost confidence in the person.
- While designing, importance should be given to the variation of body parts that are more active. Functional parts may get bigger in size compared to non-active body parts. It will lead to asymmetrical shapes, but the clothing should be designed in a way that looks symmetrical visually.
- Trousers for a wheelchair user should be designed in such a way that the length should be longer than usual since it has the tendency to rise while the person is in a seated position (Eggleston et al., 1994)
- According to Ortiz, 1992, due to pressure sores, unwanted fabrics that can create friction should be avoided. E.g., Back pockets are not to be added on lower clothing for wheelchair users.
- Strokes and Black, 2012, discuss the importance of expressive and aesthetics in clothing along with safety among adolescent girls.
- Shahani & Steffek, 2020 as well talk about the necessity of adaptive clothing being fashionable besides fitting the body well.
- Sports-specific garments for wheelchair users playing rugby should have a proper fit and should focus on regulating core temperature (Braganca et al. 2018). Importance was also given to wheelchair users' accessories like gloves.
- Compression garments can help wheelchair athletes to bring stability to the body during sports activities. It can also be manufactured with biomedical sensors as added features. Athletes with upper-body disabilities find it easier to wear short sleeve garments without having cuffs (Jennifer. A. et al., 2013)
- As per Liu and Little 2009, Olympic sport like tennis require skill, speed and endurance to perform the sport. Semi-form-fitted sportswear is recommended for tennis.
- The wheelchair tennis players need specially designed lower clothing that can have room for callipers and braces (Bairagi & Bhuyan, 2021)
- It has been observed that, preferred fabrics for adaptive clothing are durable, breathable, water-absorbent, high-performance material etc. According to Kabel (2019), warmth, comfort and safety are the most important factors for designing clothes for the differently-abled. Formal clothing is one category, wheelchair users showed interest. Much research has been carried out in the field of adaptive clothing in various parts of the world. Literature shows designing of Adaptive sportswear in the field of wheelchair rugby, wheelchair basketball, racing, tennis etc. In functionality of garments, easy donning, and doffing, providing warmth to the body, comfort, easy closures are the main requirements with many research papers related to adaptive clothing (Feng and Hui, 2021).
- Babenko L.G. et al., 2020, developed heat-protective adaptive clothing for wheelchair users. It provides thermal protection to the body.
- The sportswear designed for tropical developing nation can develop cooling sportswear beneficial for the athletes to beat the harsh sunlight (Wickramaratne & Mahmud, 2021).
- Sarah Klecker's velox project for USA team racing kit for differently abled, Tokyo 2021. The sportswear was designed focusing on the thermoregulation of the body, ergonomically design and avoiding chafing of the body with a wheelchair. (<https://www.sklecker.com/velox-spd-capstone-project>)
- Promostyl, 2021, in the sportswear category emphasizes on lightness and easy movement for better performance. Focusing on the geometric patterns and iridescent reflective designs. Sportswear fabrics are quick dry, water repellent, and proper ventilation in heat zones of the body. (<https://promostyl.com/>)

6. Adaptive Sportswear- integration of fashion and innovation

The sportswear market is growing at a very fast pace with performance as well as casual sportswear (Dhanapala, 2016). The category is available with many leading fashion brands showcasing the latest trends. Attempts have been made to keep the clothing line abreast with the current fashion trends. This gives the wearer confidence and creates a sense of belonging to the society they live in. Sometimes a limited attention is given to the psychological part where a differently-abled person might urge to be independent as far as they can, when it comes to the act of dressing and undressing (Kabel et al., 2017). The conceptual FEA consumer needs model of Lamb and Kallal, 1992, plays a significant role in creating and classifying clothing with functionality, expressiveness, and aesthetical values (Fig. 3). It explains the connection between the functionality of a garment to the culture that is associated with expression and aesthetics. This concept can be accepted for all types of apparel from functional to ready-to-wear. A problem-solving approach for upcoming designers to explore the arena of special needs.

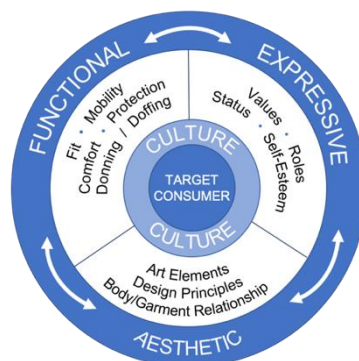


Fig. 3- FEA Consumer Needs Model (Lamb &Kallal, 1992)

To understand the design needs in sportswear of the users', an ethnographic study may be conducted with the help of participant observation during the actual wheelchair sport. According to Howell (2018), ethnography explains social anthropology that includes the method of participant observation ethnographic fieldwork. An activity that can be undertaken to get a deeper understanding of the wheelchair tennis player's psychological needs. Based on the user study, the problems related to wheelchair players can be further studied upon. Along with the user study, the researcher additionally can try to examine the peripheral areas that influence the user, the task, and the environment as mentioned by Watkins and Dunne (2016). To find out the challenges faced by the users', the first step is to carry out exploratory research to understand and make oneself familiar with the problems. To gather facts and beliefs about the problems and then go in- depth into the very crux of the problem by examining the same. Hanington, 2003, had divided the research methods for human-centred design into traditional, adapted, and innovative. In traditional research method, market survey, focus groups, surveys, questionnaires, etc. were listed. In the next adapted research method, observational research, participant observation, still pictures and video documentation, ethnographic methods, etc. In the third Innovative research methods, creative, participatory design workshops, visual diaries, camera studies, card sorting, etc. These user centric design methods can be beneficial to develop adaptive sportswear. Along with fashion, the advent of technology and innovation in sportswear has reached a new height.

7. Conclusion

In India, there are limited studies in the field of adaptive sportswear. With almost 2.21% of the population in the impairment zone in India, there is a need to focus our attention on differently-abled with respect to clothing in general and sportswear to be specific. In recent research studies in the field of sportswear, primarily focus is on functional aspects, material performance, physio thermal regulation of the body temperature and aerodynamic behaviour of the sportswear to improve performance. These factors can be adopted for the development of adaptive sportswear. Additionally, to achieve garment fit in adaptive sportswear anthropometric measurements of the differently-abled is essential. Ergonomic factors, body movement, physio thermal regulation and aerodynamic considerations need to be taken into account to make the sportswear more functional. Special seams and seamless technology may be used for functional sportswear of the differently-abled. Research needs to be carried out to understand the functional, expressive and aesthetic needs of the differently-abled for designing of adaptive sportswear. User centered research and ethnographic studies provide a theoretical framework for designing of adaptive sportswear.

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