Resistance Intravehicular Activity Clothing for Microgravity

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Introduction: Since the beginning of spaceflight with humans (in 1961,with Yuri Gagarin) nearly 600 people including paying travelers have flown above the Karman line, 100 km above the sea level, where the definition of space begins..(Schroeder et al., 2021). Different types of spacesuits are required to be worn by astronauts, cosmonauts, or space travelers for a space flight above the Karman line where the space conditions are tougher than the atmospheric conditions a human can live in. Extra Vehicular Activity (EVA) spacesuits provide protection and function to operate outside of the spacecraft for spacewalks and terrestrial or suborbital activities. Intra Vehicular Activity (IVA) spacesuits are used during pressurized environmental conditions inside the spacecraft and for emergency protection during launch, landing and during daily routine activities (Cadogan, 2017; Chang, 2021). Other than the dangers of outer space conditions, there are many health consequences as a result of being in a microgravity environment for a long time during IVAs. Major muscular atrophy and skeletal deterioration result from weightlessness as well as slowing of cardiovascular system functions, decreased production of red blood cells, eyesight disorders and changes in immune system (Neergaard & Borenstein, n.d.). Therefore, space travelers need to implement more than 2 hours of exercise per day to combat microgravity induced muscle and bone atrophy (Johnson, 2020)

As space travel advances, including the orbital space tourism started in 2001 with more suborbital fight offered by Virgin Galactic, Blue Origin and SpaceX, the need for spacewear for IVA exists where the gravity is almost indistinct or varies in range. Existing IVA clothing is based on Earthwear and environmental conditions on Earth and limited in aesthetic features offering little choice to astronauts and space travelers. This research explores the design of everyday clothing for intravehicular activities based on in-depth study of the interaction between body and clothing in microgravity environment through interviews with astronauts and literature review. The ultimate goal of this study is to create an aesthetically pleasing and comfortable resistance IVA clothing in order to implement extra muscle activation during daily routine body movements in the spacecraft to cut down the needed 2 hours training time for space travelers.

Materials and Methods: In the first phase of this study, primary sources of data were collected through interviews with a NASA astronaut and a microgravity physiology expert from International Space Station (ISS) U.S. The interviews which lasted for one hour questioned the specific muscles where most atrophy occurs, main exercise protocols for astronauts, daily routines of astronauts in a spacecraft and challenges regarding clothing. Secondary data was collected through observation of video footage of intravehicular ISS videos and an in-depth review of published studies from wide range of disciplines about microgravity conditions, changes in the body anatomy, posture and therefore interaction of the body with clothing in such environments. Based on the analysis of data collected from primary and secondary resources, design criteria for development of resistance IVA clothing were determined.

The second phase of the study, prototype development, included 1) replicating body posture in microgravity environment through a 3D digital avatar design in CLO software, 2) 3D printing of a half-scale physical microgravity posture avatar, 3) Resistance IVA clothing ideation on 3D printed avatar, 4) IVA clothing material exploration and testing. A virtual 5' 5" height female avatar was modified by Clo3D based on adjusting the joint angles to the neutral posture in microgravity environment (Imhof et al., 2013). The avatar is 3D printed using fused deposition modeling 3D printer in half-scale in 5 pieces. The pieces are then fused together with adhesive and dowel pins to ensure alignment. The 3D printed avatar then was covered with foams to make it pinnable for prototyping purposes.

Figure 1: A. Avatar in neutral body position in CLO 3D, B.3D printed half scale avatar, C. Foam covered pinnable avatar.

For ideation about the resistance IVA clothing, four way stretchy knit and non-stretchy woven fabrics were explored to establish the resistance mechanism around joints. 4-way stretch fabrics were manually tested to find the forces needed to elongate the fabric. Stretch fabric specimens were extended from one end while the other end was fixed, and the force to extend the fabric is calculated by a manual weight-meter.

Results and Discussion: The interviews with NASA professionals revealed that muscle atrophy and skeletal elongation are important complications in microgravity. Microgravity causes changes in the body form and while lower extremities get thinner, upper body get wider. The interviews also gave insight into daily life in the spacecraft such as the time spent in different activities, body parts most in use during these activities and clothing and fit needs. Duration clothing use before discard, material restrictions such as inflammability were also discussed.

Figure 2: Sleeve prototype development for neutral posture with resistance stretch on elbow joint.

Based on literature review on the changes involved in human anatomy in microgravity conditions and the interviews; antigravity muscles such as calf muscles, the quadriceps and the muscles of the back and neck (64249main_ffs_factsheets_hbp_atrophy.Pdf, n.d.) that keep the body in standing, upright position under Earth's gravity are most affected by muscle atrophy. The six movements, extension and flexions on the hip, shoulders and knee and elbows, were targeted to develop the IVA resistance clothing (Figure, 2). Stretch fabrics around the joints that work the anti-gravity muscles during these selected movements were used in initial prototyping of the IVA resistance clothing. Sleeves and legs were anchored on the hems to hands and feet to transfer the force created by muscles to the clothing. For each joint a minimal force of 3 Newtons is applied to extend or to flex fully. Even though, the force is minimal compared to the regular exercise loads of astronauts, the continuous load supplied from the garment is expected to add up though the repetitive daily activities.

Conclusion: The effects of weightlessness require a new methodology for clothing design since it is not possible to mimic drape of clothing in microgravity under earth's gravitational conditions and test functional features. This research presented prototyping process of a resistance IVA clothing to reduce exercise time in space based on findings from interviews with professionals and analysis of the literature. The resistance IVA clothing design holds the potential to decrease training time and allow more time for scientific crew activities. The future work includes tensile strength measurements, a finalized prototype, testing the muscle activation and resistive forces created by the prototype in joints during a parabolic flight for weightlessness.

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