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Statistical Validation of User Needs for Morpho-Active Auxetic Integration in Sports Protective Gear

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ABSTRACT

A cross-sectional survey quantifying self-reported barriers was piloted to using protective gear and interest in adaptive gear in multi-sport athletes (N = 53, ages 18-31+). Even though athletes reported frequent injury and near universal protection, a large proportion of users reported discontinuation, most commonly due to discomfort of protective gear. The most important limitations were restricted mobility, rigidity, poor fit and excessive heating. Equipment that adapts to body movements was preferred, which corresponds to morpho-active auxetic system. These results provide a case for further investigating the use of auxetic metamaterials to realize sports equipment that expands laterally when stretched in order to provide more conforming, energy-absorbing, and indentation-resistant protection than now possible [1][2]. In summary, the needs of athletes can be captured as a user-driven design specification for next-generation adaptive protective equipment for further biomechanical prototyping and validation.

INTRODUCTION

Sports participation is increasing world-wide and so too are sports injuries. After a 17% decrease in sports injuries in 2020 compared to 2019 (likely due to the COVID-19 pandemic), sports injuries increased by 20% in 2021 and have continued to rise over the remainder of 2024. Many of the popular team sports have a high incidence of injuries, and this is especially true in children and adolescents [3][4]. According to the National Safe Kids Campaign, 3.5 million U.S. children under the age of 15 are seen in a medical facility each year as a result of sports related injuries[4]. Lower extremity injuries are some of the most common, which is why many young athletes who participate in sports are required to wear some form of lower extremity protection, such as shin guards or knee pads[5]. Both FIFA and IOC mandate that football players wear shin guards at all times. Research into the effectiveness of football protection products like shin guards and knee pads has shown them to be effective in the reduction of contusion and laceration injuries[6]. Although they have not been proven to have a significant impact on the occurrence of catastrophic tibial fractures, they have not been proven to be ineffective, either. Given the increasing number of children participating in youth sports, as well as the increasing number and duration of practice sessions, it can only be assumed that improved protection for young athletes is needed to decrease the increasing burden of sports injuries in this population[7].

Protective gear (PG) is used in many different sports but is often poorly adhered to. The sports equipment can be heavy and cumbersome and the athletes may not like the bulky apparel. A study on young football players showed that although 96% stated that they wore their shin guards whilst playing football, they were often taken off due to heat stress and restricted movement [8]. A study conducted on the effects of PG on university athletes found that they limited range of motion and resulted in a drop in athletic performance[8]. The athletes believed that the PG "increased safety" but were not inclined to wear it due to discomfort, lack of alternative gear and referee enforcement[9]. Protective gear compliance in high-impact sports can be as low as 90% despite evidence that the use of PG reduces injuries and the severity of those injuries[10][8].

Sports protective equipment is required to reduce shock and to provide the highest possible performance to athletes. Current products are made of rigid foams and hard plastics, which are suitable for shock attenuation but do not take into account the movement of the human body. This results in the performance-protection paradox where the best products for shock attenuation can lead to the greatest number of injuries as they restrict athlete movement. New material concepts are required to improve current sports protective products. Auxetic metamaterials have a negative Poisson's ratio and expand laterally when stretched and contract when compressed [1][11]. They can therefore provide form-fitting compliance required for sports protective products. For example, an auxetic pad can spread itself into a concave cavity of the body. Auxetic foams and textiles have been shown to offer high shock attenuation, good compliance and adaptability to complex shapes of the human body and therefore can be used as a core material for personal protective products [1][2].

Morpho-active surfaces take this technology to a new level. By using auxetic/origami patterns that change shape as you move or are loaded – without the need for any electronics – an auxetic lattice can stiffen only where it is required (around the impact point) and bend and flex around joints. The designs can be based on intricate biological structures, such as the skin texture patterns, or the scales of a butterfly's wings. For sports equipment the morpho-active surfaces would create a full range of motion at joints and vents, but would instantaneously stiffen at the point of impact to provide protection to the wearer.

LITERATURE REVIEW

Year after year, studies reveal how deeply sports injuries affect both people and budgets. Across wealthier nations, medical visits tied to youth athletic harm number in the millions every twelve months [4]. While expected rough games - such as football, rugby, hockey - bring frequent harm, less intense activities like cricket or running log more damage too, especially as more join in [3][7]. Data mapping research trends proves one thing clear: society now treats sport-linked physical setbacks much like any widespread health concern. Every time someone plays contact sports, wearing protection helps right away. In soccer, players must wear shin guards - rules say so [5]. Research shows these guards actually lower small injuries like bruises and scrapes on the lower leg [6][10]. When it comes to cricket or hockey, padding for knees and elbows takes the hit from balls or sticks. That cushion cuts down damage to muscles and skin. Still, safety tests for padding usually check only for cuts and surface wounds, overlooking defense against serious breaks. Because of that, major bone injuries happen anyway during hard hits or bad tackles [6].

Comfort matters just as much as protection when it comes to sports gear. Though research shows most athletes believe equipment keeps them safer, many still skip using it regularly. A study from IRJAHSS revealed college players agreed on safety benefits - however, real-world use hinged heavily on how the gear felt during play. Bulky designs made motion harder. Trapped heat became a problem mid-game. Some quit wearing items because cleaning was tough or materials wore out too fast. Fit played a big role, not just function. Even well-made gear gets ditched if it slows someone down. Sweat soaked pads lost appeal after only a few uses. Players kept returning to older styles they could move freely in. Design flaws outweighed safety promises every time temperature rose. Long-term trust depended less on lab results and more on daily experience. Despite common belief, poorly designed gear hampers movement and delays responses, according to ergonomic studies [8]. When wearables feel heavier or hotter, choices shift - reports show comfort, price, or bulkiness drop adherence sharply, from nearly universal down below ninety percent [9][8].

This is where an oddity appears. Designers typically focus on numbers when creating equipment, such as how hard something hits or how quickly it reacts. However, users are more concerned with how it feels and works when they're playing. Recently, experts suggest that when creating sports tools, users should come first. Comfort is very important. It also looks good. Specifications on paper may not be as important as your belief in what you're wearing. Put on safety pads for football. New products reduce weight, make use of better fabrics, and facilitate mobility. However, if they have self-doubt, don't take pride in their appearance, or simply find perspiration bothersome, they abandon them. Sometimes, trust influences behaviour more than facts.

A percentage of the issue may be resolved with the use of smart materials. According to reviews, some foams and structures—those that expand when stretched—manage impacts significantly better than standard foams[1][2]. Particular auxetic designs for wearables bend easily, distributing force uniformly and absorbing energy. Instead of resisting movement, these padding systems adapt, staying comfortable under pressure. Clothing made with stretchy inward fabrics fits snugly around curves, improving contact without tightness. Research points one way forward: protective layers that give slightly during motion yet stop shocks effectively. Still, nearly all research focuses on machines - running simulations or smashing materials - instead of people. What's missing? A solid link between new fabrics and real users. Think about it: just because something stretches well sideways or resists dents in a lab doesn't mean athletes care. Those features must line up with what matters most when running, jumping, sweating. Lab numbers alone won't tell you that.

Overall, research indicates youth and amateur sports injuries are increasing[4]. Protective equipment helps reduce minor harm yet often fails to stop severe breaks[6]. Poor comfort along with improper fit tends to discourage consistent use of safety gear[9][8]. This work stems from those insights - using statistical review of athlete experiences to measure obstacles tied to such designs[1][2].

METHODS

Study Aim

This research checks how strongly athletes, coaches, and casual players link their real-world issues with protective gear to a willingness to try new responsive equipment. Findings highlight patterns across football, basketball, and cricket where comfort gaps shape preferences. Responses from 41.5 percent of leisure participants show recurring problems often ignored. Adjustments in fit and movement play into whether upgrades feel worthwhile. Personal feedback shapes safer builds that match actual motion demands. Some designs miss marks during quick shifts on field. User voices steer subtle improvements reducing strain over time. New forms take cues from body behavior under stress. Gear evolution leans heavily on lived experience rather than lab assumptions.

The study method that is adopted is mixed methods which help in validating the information through the numbers. The interviews were conducted with the players and trainers that gave insight into the variables that should be added to the questionnaire like comfort, warmth, movement etc. These variables were turned into multiple questions in the Google form and were filled out by the players who were involved in multiple sports like football, basketball, cricket etc. All the participants were asked for their consent before filling out the questionnaire to meet the ethical guidelines.

Participants

The total number of participants was 53, which is quite a decent number. The participants included players which were full-time and also part-time (semi-professional). Also those who played sports for recreation (Recreational Players). Coaches were also part of the participants as they are in close interaction with the players and also, they were past players as well. The variety in participants gave an insight on multiple user perspective. The age of the participants was from 18 years to 31 years. The target community's sports participation demographics are roughly reflected in the sample distribution.

Data Collection

The questionnaire had a multiple choice format that explored five main aspects: (a) the frequency of the use of protection equipment, (b) the self-declared injuries, (c) the limitations reported by athletes to the current protective equipment—relating to the freedom of movement, the size of the equipment, as well as the heat and humidity sensation experienced when wearing it, (d) the reasons for removing this same protective gear, and (e) the interest in using adaptive protection equipment such as smart protective equipment (which allow a little adjustment or regulation to the body of the athlete, aiming to achieve an optimal fit and comfort) or custom-made (made in a specific size to the athlete's body measurement to achieve an optimal adjustment). The majority of the questions were based on a Likert agreement scale ranging from 1-5.

Level of involvement distribution

The participants in the study have upbringings in a variety of different sports, and most regarded themselves as competitors. Recreational players in percentage were **41.5% (n = 22)** of the user activity type, second were semi-professional athletes with **39.6% (n = 21)**. Just **1.9% (n = 1)** are coaches or trainers, and just **7.5% (n = 4)** are professional athletes. Furthermore, **9.4% (n = 5)** of the sample reported not participating in sports on a regular basis, creating a sedentary baseline for the data set.

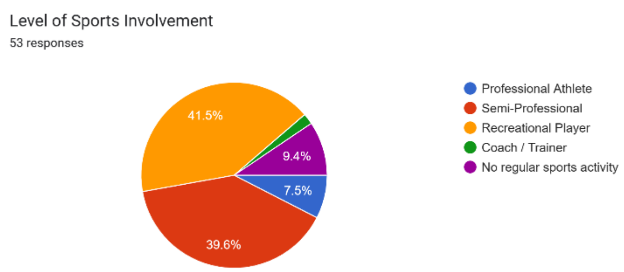

Figure 1. Level of Sports Involvement

Approach to eligibility and inclusion

The original plan, along with a specific age range, was shaped by active participation in sports using or recommending shin, knee, or elbow gear. Still, the actual rollout pulled in wider input - some people joined even without consistent athletic routines. Seen not as a flaw but a deliberate stretch, this widened scope possibly blurs sharp conclusions about sport alone. Such effects appear later, weighed through focused tests and noted where limits show.

Measures and instruments

A set of questions covered age and background, along with sports involvement. Equipment habits were checked through gear-use patterns. How discomfort happened came up during responses about physical strain. Past injuries shaped answers on health events. Times when devices weren't worn appeared in behavior reports. Attitudes showed up across ten focused statements.

Demographics and participation

Young people filled out most forms, though older adults joined too. From under eighteen up past thirty one split how ages showed up, while some marked male, others female, a few skipped that part entirely. Participation shaped roles - some earned paychecks from play, others played weekends only. A handful led teams or guided workouts without competing themselves. Not everyone moved much at all; several stayed on the sidelines completely.

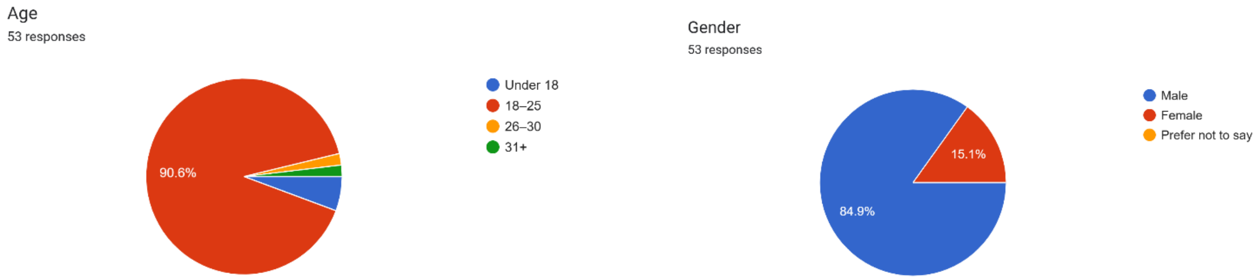

Figure 2. Demographics

Furthermore, figure 3 shows that each participant specifies the exact sport they played, which opened up ways to study results across different fields.
When it comes to playing sports, most people in the study lean toward games with teams. Football stands out clearly, showing up in **71.7%** of answers - that's 38 individuals. Close behind is cricket, pulling in just over a third at **35.8%**, which adds up to 19 people. For those who prefer going solo, running takes the lead, chosen by roughly every fifth person surveyed. Some also play basketball, seen in **15.1%**. Others split between tennis and volleyball, each named by **11.3%**. Notably absent are skateboarding and hockey - not a single participant listed them. A few wrote in less common options like squash or badminton. Because many take part in more than one sport, the numbers overlap, hinting these folks stay busy moving their bodies in different ways.

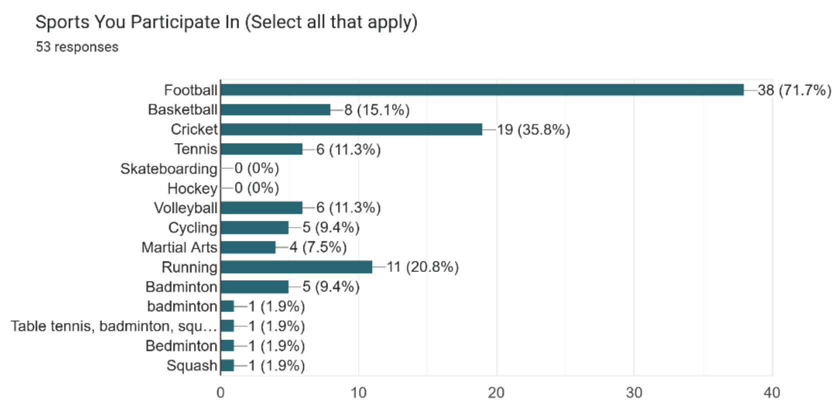

Figure 3. Participation in Sports

RESULTS

Protective gear usage and perceived gaps screening: Protective gear usage and perceived gaps screening People wear safety gear. That does not always mean they feel safe. Looking at how often protection is used gives clues about where worries stay strong. When fear stays high even with equipment on, something is missing. No matter what is worn, some body parts continue to be identified as weak points. Patterns reveal errors. Even though some areas are well-covered, they are still feared. Some areas are thought to be dangerous and are barely protected. The numbers show a gap in the assessment of preparedness. It is not necessarily true that what is felt to be unsafe is what is being used. Gaps are evident in instances where coverage surpasses trust. These instances show a gap in the assumption that equipment translates into trust. Wearing clothes is just a form of protection.

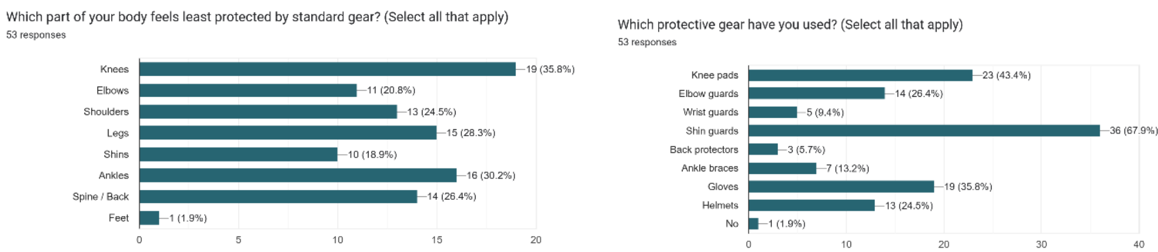

Figure 4. Protective gear usage and perceived least-protected body areas

There is a disconnect between the protective gear that people use and their perceived areas of vulnerability, according to the survey data **(n=53)**. Shin guards were found to be the most popular, with **67.9%** of respondents using them. Next were knee pads, with **43.4%** using them. Nevertheless, there were still complaints about these areas. Specifically, knees **(35.8%)**, ankles **(30.2%)**, and legs **(28.3%)** were found to be those parts of the body that felt "least protected" even though there was extensive protection of these body parts. There is a disconnect here. There is one area where there is clearly a disconnect: spinal cord protection. Only **5.7%** of respondents reported using back protectors. Nevertheless, **26.4%** reported that their regular gear did not offer adequate protection for their back and spine. The same is true with ankle protection. Only **13.2%** reported using ankle braces, while **30.2%** reported these parts of their body as being vulnerable. This could mean that athletes believe that current market-available gear is not sufficiently protective, or that such gear is not being used sufficiently in these critical areas. At any rate, there is a disconnect between athletes' complaints about their protective gear and what is actually being worn.

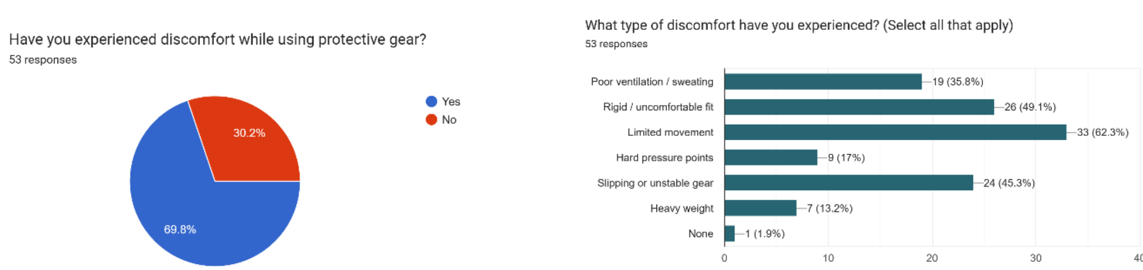

Figure 5. Discomfort experienced with protective gear

Analysis of User Discomfort and Injury History: However, in order to understand why this is still happening, it is necessary to look at the experience of the athlete as well as the use of equipment itself. It is necessary to look at the relationship between what this equipment is designed to do and where a person feels vulnerable on their body. This will allow for a better understanding of what it means for the athlete to have to choose between performance and protection. A significant majority, **69.8%**, of those surveyed felt uncomfortable when wearing protective equipment can be seen in figure 5. This suggests that perhaps the athlete is being hindered by this equipment.

Figure 6. Injuries and affected areas

Figure 6. illustrates that the most common concern was limited movement, total for **62.3%** of all complaints. At **49.1%**, a stiff or uncomfortable fit came next. Then, at **45.3%**, unsteady or slipping gear. Sweating and non-breathability affected more than one-third of the sample **(35.8%)**. Additionally, this increases the chances that users will remove the equipment during high strength activity.

The statistics in figure 6. shows previous sports injuries and how protective gear led to those injuries. To assess whether standard gear fails due to mechanical failure, poor ergonomics, or design problems, it is important to consider the context in which the injuries occur. This is possible by observing the context in which the current safety gear fails through the injury points and the reasons for failure as perceived by the users. **94.3%** of respondents claimed they experienced an injury related to sports. The injury points included legs **(49.1%)**, knees **(43.4%)**, and ankles **(37.7%)**. This corresponds with the regions that respondents reported feeling "least protected."

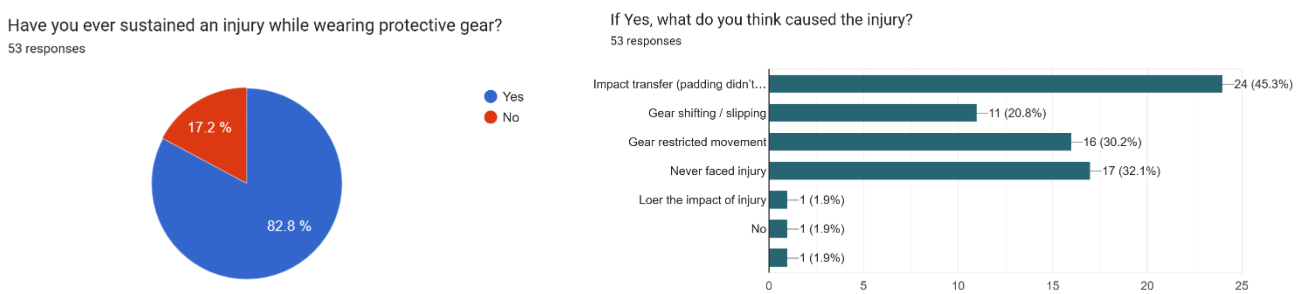

Figure 7. Injuries and affected areas

What is even more surprising is that **82.8%** of the participants got injured while using the protective gear. This means that in most cases, the protective gear failed to prevent injury. Impact transfer was the reason cited by **45.3%** of the participants for the failure of the gear. This is because they thought the padding failed to distribute the impact.

From the above figure 7., it can be demonstrated that **20.8%** mentioned the equipment's shifting or slipping. Yet another **30.2%** of the participants said that the equipment restricted movement, which caused the injury. This is a paradox. Most of the standard equipment does not provide any absorption. On the other hand, ergonomic problems, which include restricted movement and instability, may also increase the risk of injury by getting in the way of a defensive move.

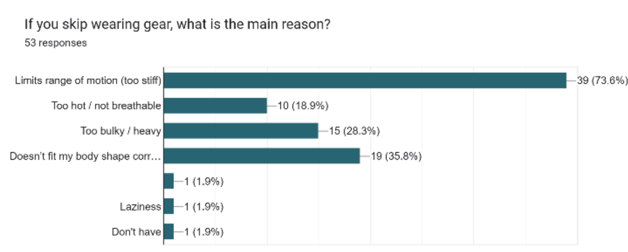

Figure 8. Reason for not wearing PG

Beyond stiffness, **35.8%** said the equipment does not fit their body shape correctly, which further discourages consistent use.

DISCUSSION

We validated a large, user-specified performance gap relative to the current performance of sports protective equipment. Although our study population wears sports protective equipment frequently, they experience frequent complaints of musculoskeletal discomfort and non-use due to restricted movement

(73.6%), ill-fitting protective gear (45.3%), and heat (35.8%). Discomfort ratings were verified, as well as the reasons for non-use of the protective gear and relative importance of each attribute to users. Present day protective gear is currently defined by standards to provide a level of impact protection adequate to the risk in the particular sport. From our findings, however, the current designs are strictly mechanical and do not provide any consideration to the ergonomic aspects of the protection afforded. This large performance gap and resulting non-use with our population is confirmed as only 9.4% of users reported wearing their protective gear for all activities.

According to the research study, 94.3% of the participants had suffered from multiple sports injuries and 82.8% of these injuries were sustained while wearing some form of protective gear. Further analysis revealed that the most common reasons for failure of the protective gear were impact transfer (45.3%) and restricted motion (30.2%). The study highlights the inadequacies of present day rigid materials used in sports equipment. These materials are unable to dissipate the shock loads generated during an impact effectively and also hinder the natural defensive movement mechanisms of the wearer.

Although the theoretical mechanical benefits of auxetic materials have been proved (i.e. elasticity and shock absorbance), very few studies exist which explore the user needs for auxetic materials and their applicability to sports (in the context of Pakistan for football and cricket and attitudes towards auxetic materials). This research aims to explore the validity of the concept of auxetic materials in the context of sports in Pakistan, and understand design parameters that affect auxetic materials significantly, especially the fit and mobility of the materials, and explore ways to address them by integrating morpho-active auxetic systems.

Well we now have the results of our survey and, unsurprisingly, it seems people are open to the idea of innovation, and that functional fitness is a key trend in the world of movement and exercise, with a desire for clever, movement-based fitness systems, and an interest in wearables that can be tailored to an individual's needs. This is basically what we predicted based on the theory behind the use of auxetic materials and our concept of morpho-active design, but it remains to be seen whether this translates into real life, high performance products and so the work of designing, building and testing prototypes, and conducting biomechanical testing will be essential to verify these assumptions.

Limitations

Sample bias - the sample was heavily skewed toward the 18–25 age group and toward men.

Lack of a sports-playing control group in the study sample means that the results are relevant to other, more representative populations of stakeholders, and so cannot be used to infer with certainty the impact of brain injury on athletes. The results should therefore be treated with caution and further analyses (such as subgroup analyses or sensitivity tests) should be undertaken in order to determine their relevance and applicability to the sporting context.

Skip-logic leakage in the injury-cause follow-up needs to be dealt with by applying cleaning rules and corresponding reporting.

Self-reported injury mechanisms reflect perception rather than clinical verification.

Our findings are based on a relatively small sample, which restricts the scope for more elaborate psychometric analyses and conclusions should be treated with caution. The EFA results should be interpreted with care, and with a full consideration of the diagnostic plots.

CONCLUSION

The survey showed the frequent but uncomfortable use of sports protective gear, as well as a demand for improved mobility, fit stability and reduced thermal burden from users of sports protective gear. Participants support movement-conforming, adaptive solutions that include new materials and technologies, as long as a noticeably greater level of comfort can be provided.

These findings provide evidence-based requirements that justify the development of morpho-active auxetic integration for shin guards, knee pads, and elbow pads. This user-led evidence base will lay the foundations for the next stages of this study namely the design and manufacture of prototypes and the use of biomechanics to validate the performance promises of these auxetic systems.

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