Improving Grip Efficiency in Wheelchair Athlete

Propulsion Through Directional Surface Patterns

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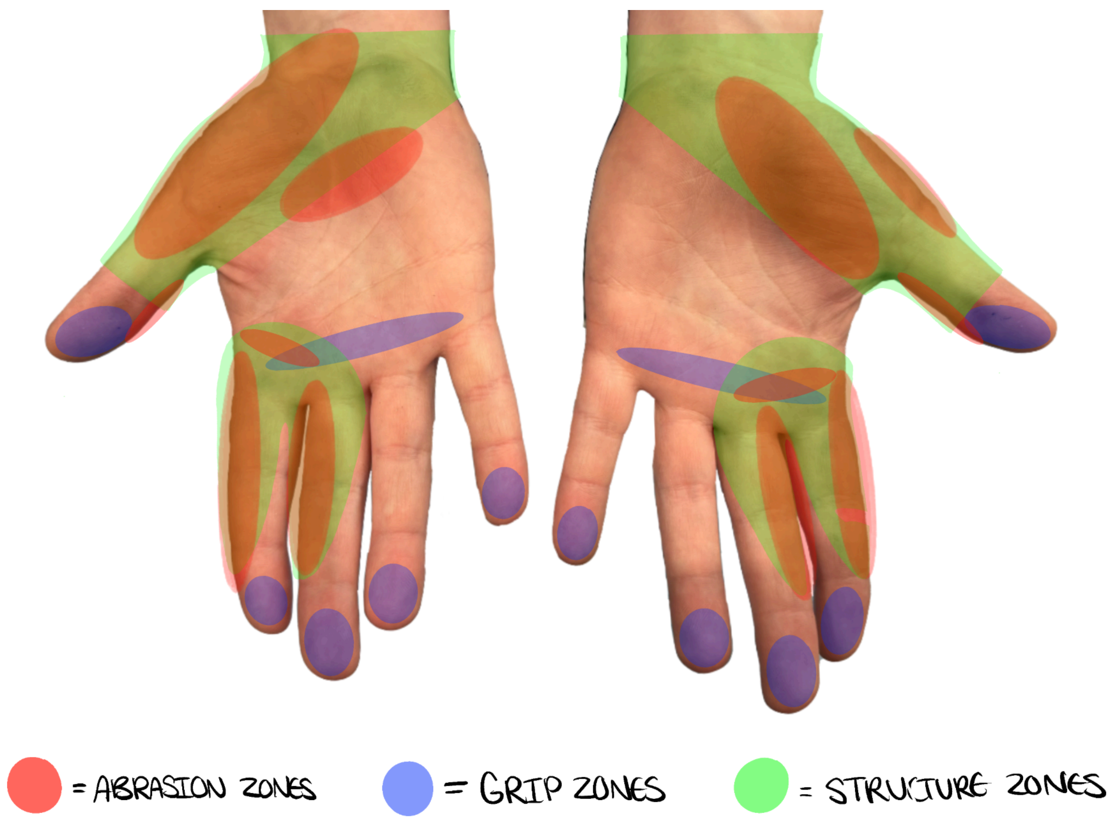
Athletes in wheelchairs rely on repeated hand contact with the pushrim, wheel, or often a combination of both, to generate forward propulsion. This makes grip efficiency a critical factor in both performance and overall physical health. When an athlete who utilizes a wheelchair goes to move, their hands must produce sufficient traction against the rim of their wheelchair to transfer force to the wheel which allows a smooth release as the propulsion cycle repeats. This extremely repetitive interaction places large amounts of stress on the hands and arms of the athlete causing fatigue, overuse sores, and repetitive strain injuries (Vanlandewijck et al., 2001; Boninger et al., 2005), impact zonal map synthesized in Figure 1. Because friction governs how effectively forces are transferred between an athlete's hands and their wheelchair, understanding how surface interactions influence grip is essential for improving propulsion efficiency and protecting athletes' hands (Bhushan, 2018). Research in tribology and surface engineering has shown that surface texture, size, shape, and orientation of grip can significantly influence performance when placed in high contact zonal areas of an athlete's hand. (Bhushan, 2018). When an athlete protects their hands by covering high abrasion zones, the loss of tactility to the rim of their wheelchair can be detrimental to their performance and pace of play. Understanding the impact of frictional behavior and grip materials will allow us to design a set of grip structures that will not only protect the athlete's hands but will also offer affordances in improving how their hands grip, slide, and release during contact with their rims. These findings suggest that designing an informed grip surface on protection patches for an athlete's hand can offer new opportunities to improve hand to surface interaction in wheelchair propulsion. Directional surface textures that control friction interaction can be adapted from biomimetic and tribological research to improve grip efficiency and reduce hand abrasion for athletes in wheelchairs. The biomechanical movement of an athlete in a wheelchair is represented through a croquis illustration in Figure 2.

Figure 1.

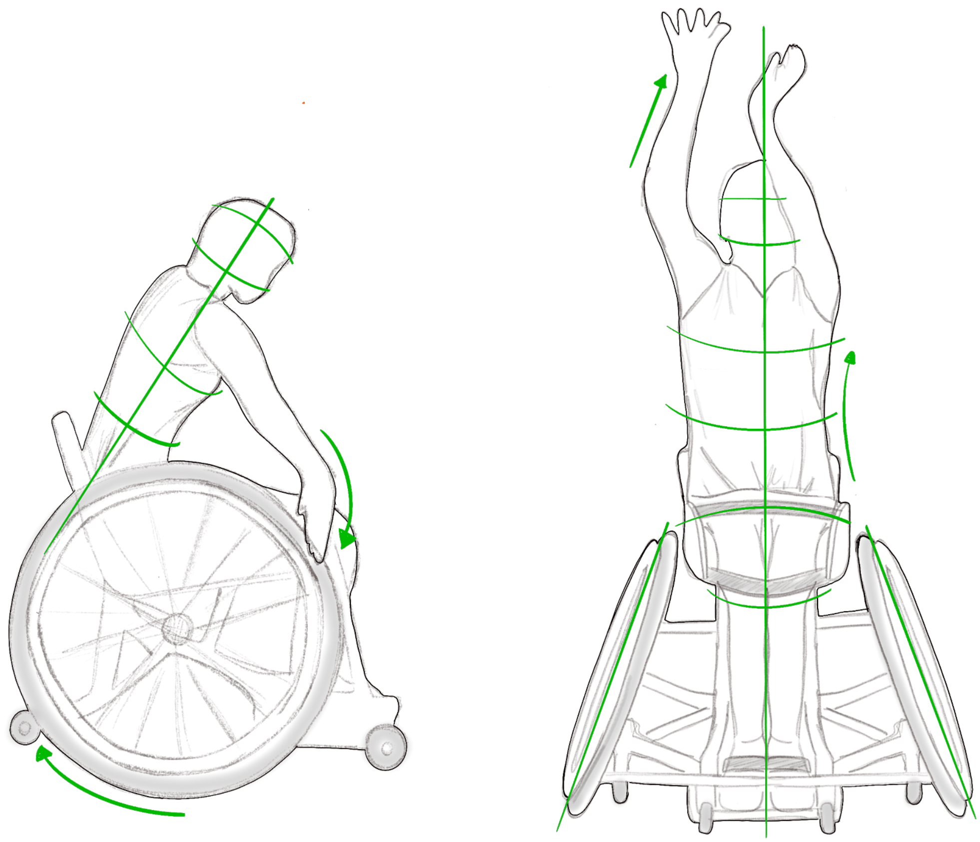
Zonal map of a wheelchair athlete's hands identifying key contact regions during propulsion. Abrasion zones (red) indicate areas of high friction and skin wear, grip zones (blue) show zones responsible for traction during push phases, and structure zones (green) represent areas where protective or performance-enhancing surface structures may be applied.



Note. Original digital illustration created by author using Photoshop 2025 and Procreate on iPad Pro.

Figure 2.

Two primary biomechanical propulsion movements of a wheelchair basketball athlete.



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Friction is the resistive force that occurs when two surfaces move in relation to one another. In many practical applications, friction is a crucial factor in determining how effectively force can be transferred between surfaces. The scientific study of friction including wear and lubrication is known as tribology and this field has demonstrated that surface geometry significantly influences frictional behavior (Bushan, 2013). While friction is often described and thought of using simple coefficients, the underlying interactions between surfaces, especially when one of those surfaces is human skin, are far more complex. Surface texture, materials, contact areas, and deformation all contribute to how two surfaces interact during sliding or gripping motions (Bushan, 2013).

Research on microtextured surfaces has shown that designed surface patterns can have a large impact on frictional performance. Studies examining microstructured polymer surfaces have shown that patterned textures and their orientation can reduce friction compared to smooth surfaces by altering contact areas (He et al., 2008). Specifically, micro scaled ruts, grooves, and other patterns can increase the effective contact area between two surfaces. Surface examples could be, both the protective grip patch on an athlete's hand and the pushrim of their wheelchair. When forced together they could produce the ability to increase propulsion power at the start of a push and reduce drag in transition from the end of a push back to the start. Different surface and textural modifications influence how surfaces slide, grip, and release during motion (He et al., 2008).

Surface texturing also affects how different materials perform under different environmental conditions. At small scales, or in a micro grip orientation such as on the hand protection patches, forces between surfaces become important contributors to frictional behaviors. By altering the surface structures or orientation, researchers can alter the balance between adhesion and forces created by physical surface textures gripping another surface. For example, tire tread gripping the road or grooves on the outsole of a shoe. These textured surfaces can increase or reduce friction based on the way their physical surface grips the surface beneath it. These findings highlight that friction is not simply a property of materials but is important to consider in surface geometry and patterning (Bushan, 2013).

Understanding how surface textures alter friction creates a foundation for exploring more advanced concepts like directional or multi axes friction. If surface structure orientations can influence friction in general, then it's possible that certain surface geometries can contribute to frictional forces in specific directions. This idea leads into the concept of anisotropic friction, where frictional forces vary depending on the direction of motion (He et al., 2008).

Anisotropic friction, also known as directional friction, occurs when the frictional response of a surface changes depending on the direction of movement; for example, a hand gripping a pushrim and pushing in a half circular motion. The surface contact at the start of the propulsion to the end is fundamentally different because the directionality of the push changes as it curves with the circular wheel shape. Unlike isotopic or static friction, which behaves similarly in all directions, anisotropic surfaces contain a structural or oriental feature that favors a motion in one direction while resisting motion in another. These directional differences arise from gradual shifts in surface geometry, orientation and contact mechanics that influence how frictional forces develop across surfaces (Qui & Li, 2024).

Research in surface interaction has demonstrated that anisotropic friction can significantly increase propulsion when correctly oriented on the surface of an athlete's hand as it contacts the pushrim of a wheelchair. Surfaces designed and engineered with directional friction in mind have been shown to generate controlled momentum, allowing structures to rotate based on differences in frictional resistances across a surface throughout a given motion. (Qui & Li, 2024)

Directional friction can arise from thoughtfully positioned surface geometry with patterned microtextures. When a surface is moving in one direction and a grip structure slides across the same surface in the opposite direction, these structures may slide smoothly over the opposing surface producing relatively low resistance. However, when motion occurs in the opposite direction the same features can interact with the surface resulting in greater frictional resistance. Studies of different patterned surfaces have shown that geometric structures and orientation can produce measurable directional differences in friction depending on the direction of the applied force (Lee et al., 2025).

The concept of directional friction is particularly important to applications that require strong traction during one phase of motion, such as the start of a propulsion (or push), and reduced resistance during another, such as at the end of a push when hands are letting go of the pushrim and reorienting themselves to start another push forward. These repetitive motions benefit from surfaces that provide high friction during one force of application but allow smoother sliding and less resistance during the latter half of the release movement. Essentially high friction when pushing and low friction when releasing.

Biomimetics is the process of drawing inspiration from nature's biological systems in order to develop an engineered system that attempts to replicate a naturally found functionality (Bushan, 2012). When looking in nature, you can find many examples of surfaces that naturally utilize their own unique structural features to control friction and adhesion. For example, a geckos' toe pads, that can include grips, patterns, or textures that allow them to move efficiently in complex environments and situations (Shahsavan et al., 2017). These biological systems have inspired designers and engineers to develop different material pattern studies to replicate different aspects of these features and give humans some of the same functional advantages found in nature.

One of the more well known natural directional frictions found in nature occurs in snake skins. Many snake species have ventral scales that contain micro patterns that generate anisotropic friction which allows the snake to move forward efficiently while simultaneously preventing it from slipping backward. The snake scales interact with the surface below them in a way that enhances traction during forward motion and reduces resistance to movement in other directions. Researchers have had success replicating similar structures using specific geometric patterns to study how surface geometry influences frictional performance (Bhushan, 2012).

Other arachnids and insects have also been known to demonstrate remarkable friction mechanisms engaged through different directional movement. Many species possess specialized hairs or adhesive pads that can allow them to adhere to vertical or sometimes even inverted surfaces. The structures for these abilities often consist of complex hierarchical patterns that maximize contact areas. As Wolff and Gorb explain, biological attachment patterns can rely on a wide array of conditions found in the wild including "friction, dry and wet adhesion, cohesion, mechanical interlocking, suction and penetration” (Wolff & Gorb, 2016, p. 1). Taking the typology from these naturally occurring biological systems, we can replicate similar applications for wheelchair athletes who, like many organisms found in nature, need enhanced grip while also maintaining the ability to detach from a surface quickly.

Biomimetic research shows that natural surfaces perform better because of structural design rather than simply complex materials (Hale et al., 2020). Many biological surfaces are composed of relatively simple materials but when organized into an advanced structure pattern with proper orientation, those surfaces can achieve incredible functionality (Bhushan, 2012). By replicating these same principles and typology, designers and engineers have the capacity to create surfaces that mimic the frictional behavior observed between organisms and natural surfaces. These insights have been a driving force in the patterning you see on the adhesive systems to protect wheelchair athletes' hands and improve their game play (see Figure 3).

Figure 3.

Conceptual hand adhesive system with biomimetic surface patterning designed to improve traction between the hand and wheelchair pushrim while protecting high-abrasion zones.

Note: Original digital illustration created by author using Rhino8 and rendered using Keyshot.

This is not the first time that forms, surface textures, and directional friction ideologies have been pulled from nature into man made products. Many engineered products use similar principals and strategies to achieve similar effects found in nature to improve traction and control. A prominent example of where these patterns and systems are found is athletic footwear.

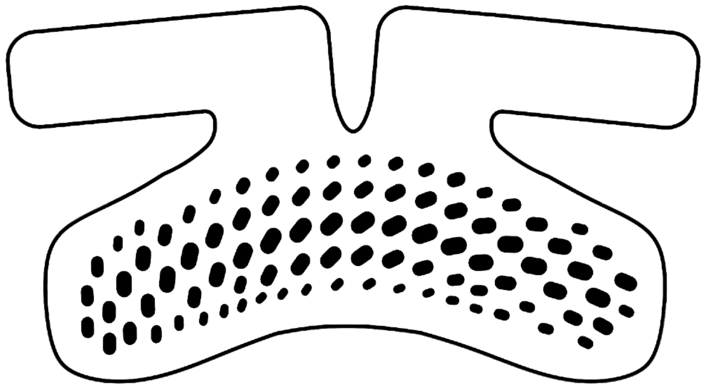
Athletic footwear provides clear examples of how surface geometry influences frictional performance. (Hale et al., 2020) Think for example you're rallying a tennis ball back and forth with an opponent and you're running to your left to hit the ball back and then a moment later you're needing to change direction and run to your right. The tread on the bottom of your shoes is producing directional friction to better help you change direction from one movement to the next. This is known as tribology, which shows how engineered surface textures can effectively "control friction and wear under specific conditions" (Ballesteros et al., 2021, p. 2).

Some sports such as basketball and tennis incorporate footwear that utilizes tread patterns designed to enhance traction for quick movements or pivots on hardcourt surfaces. These patterns often consist of repeating grooves such as herringbone patterns, commonly recognized as a consistent "v" pattern. This increases friction and traction during dynamic movements such as running, stopping, or changing direction. Studies of engineered surfaces demonstrate that friction can be controlled through thoughtful design of "ordered topographical patterns" that control surface interactions (Hale et al., 2020).

These designed traction patterns show how surface geometry can manipulate frictional behavior in several different practical applications. The same principals used to improve traction and grip on the bottom of athletic footwear could potentially be applied and tested on grip systems where force transfers occur such as in wheelchair propulsion (see Figure 4).

Figure 4.

2D Traction pattern and orientation illustration

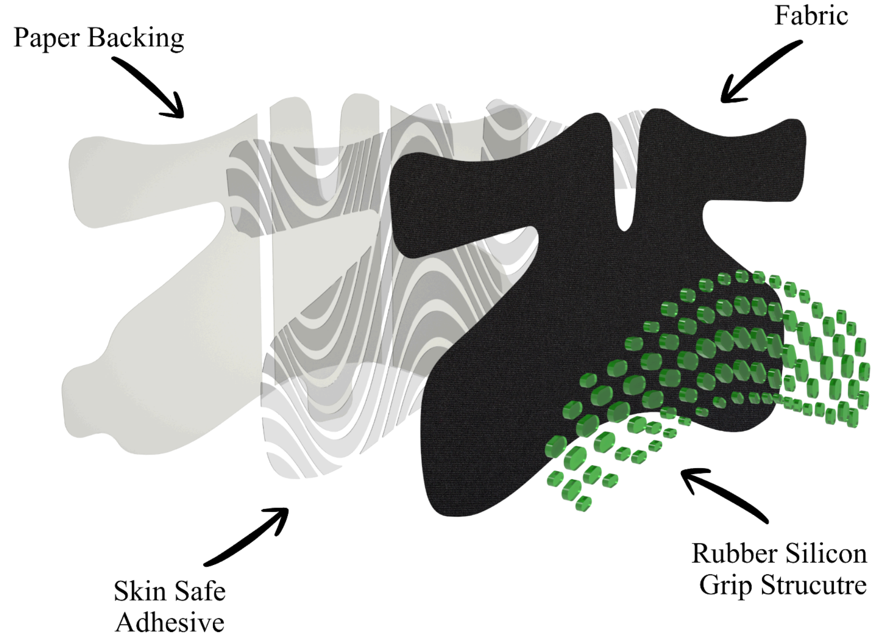


Note: Original digital illustration created by author using Adobe Illustrator 2025.

In some instances material properties can have an influence on grip performance. Soft materials such as elastomers, for example some natural, silicon, and EPDM rubbers, have the capacity to deform under pressure which increases the effective contact area on the adjacent surface because the "squish" of the material widens the surface area of the elastomer (see Figure 5). This property explains why rubberized materials are such a commonly used material on surfaces that require grip such as tools, pens, sports equipment, shoes, and more (Dzidek et al., 2017). These elastomeric materials create contact with a surface during friction so when force is applied, the object moves in the intended direction with very little or no slipping.

Figure 5.

Exploded illustration demonstrating potential material layering for protection patch.



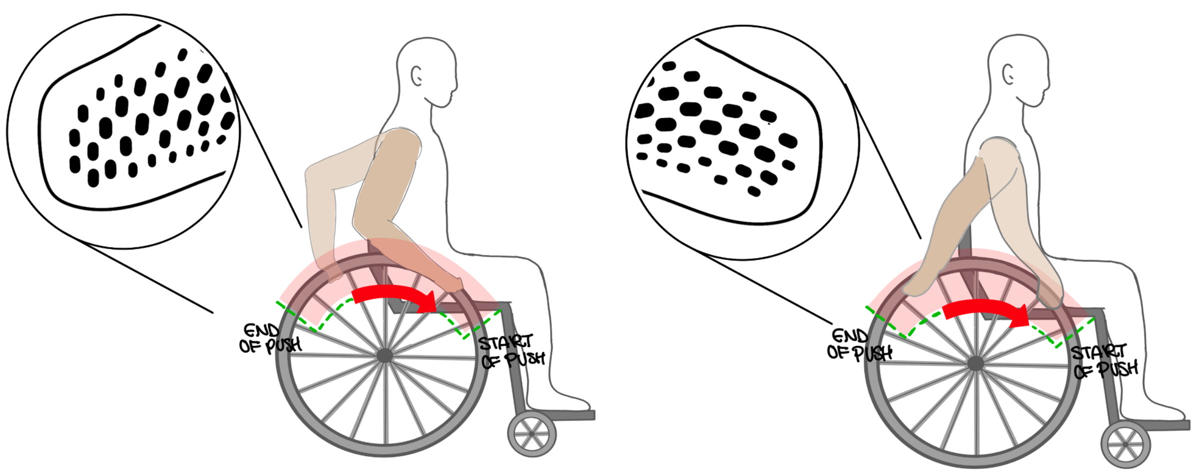
Note: Original digital illustration created by author using Adobe Illustrator 2025.

Understanding the mechanisms of human grip is important for predicting how grip will be affected when a specific area of the hand is covered and how alternative surface structures may be designed to mitigate the loss of tactility by providing a solution that results in greater friction than the skin that's covered. By understanding how surface structures can be reengineered to control friction while providing a comfortable covering of the skin, we can create new opportunities to improve manual propulsion performance for athletes in wheelchairs (Yadav et al., 2025).

Manual wheelchair propulsion, especially during sport, requires repeated cycles of hand contact with the pushrim/wheel to generate forward momentum. During each propulsion cycle the athlete grabs the rim with their hands behind their shoulders and applies force by pushing their hands and arms forward to accelerate the wheelchair to make forward progress. Once their elbows have been fully extended the athlete releases the pushrim and before pulling their arms back to start the process all over again. The change in hand orientation and frictional interaction with the pushrim throughout the propulsion cycle is illustrated in Figure 6.

Figure 6.

Hand orientation and frictional grip interaction during the wheelchair propulsion cycle.



Grip **perpendicular to the rim** at the start of a push increases friction and generates force.

Grip **parallel to the rim** at the end of a push decreases drag decreases transition time for the next push.

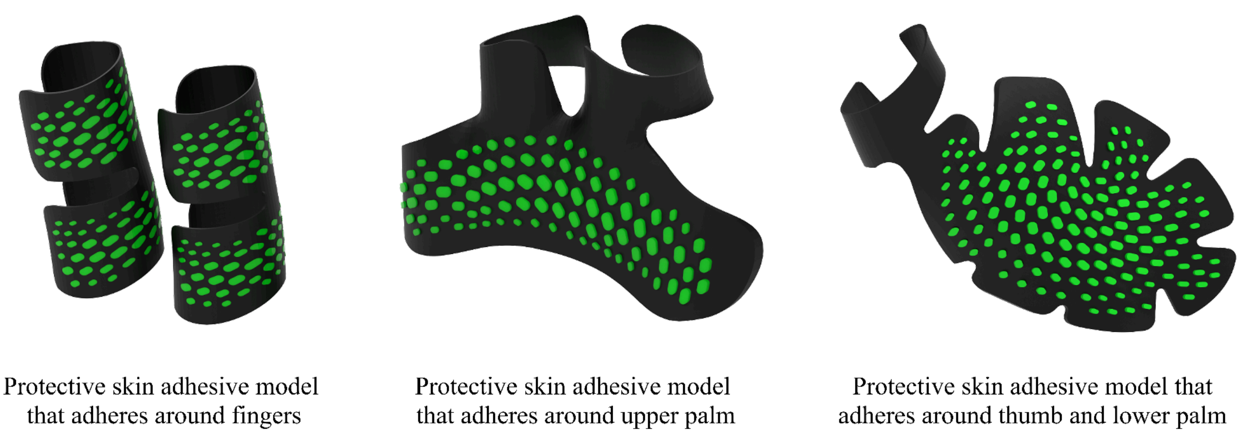
Note: Original digital illustration created by author using Procreate on iPad Pro.

Athletes rely mainly on coordinated movement of the shoulder, elbow, wrists, and hands to generate proplosion forward. The first half of this propulsion cycle involves pushing which is done by transferring force from the hand to the pushrim which propels the athlete forward. The second half of this propulsion cycle is the recovery phase, which is when the athlete has fully extended their elbows and then pulls their arms back, gearing up and repositioning for the next stroke forward (Bhushan, 2019).

When propulsion is repeated many times during a game or sporting event small inefficiencies in grip mechanics and skin abrasion can lead to diminished performance throughout a game or match. Research has documented a high risk in athletes who utilize wheelchairs for repetitive strains, joint breakdowns, skin abrasions, and more. (Dzidek et al., 2017). Improving the efficiency of hand-rim interaction with the help of hand skin adhesives with engineered grip structures may help to reduce these stress injuries, improve long term comfort, and heighten in-game performance (see Figure 7).

Figure 7.

Protective hand second skin adhesive patches with grip structures.



Note: Original digital illustration created by author using Rhino8 and rendered using Keyshot.

In conclusion, manual wheelchair propulsion places a lot of physical demands on athletes' upper body and hands. Propulsion relies on repeated cycles of force and pressure to move themselves forward. The ability to protect an athlete's hands while simultaneously improving the frictional force they can generate to move around is essential for their own long term health and their ability to have longevity in their sport. Research in tribology, biomimetic surfaces, and biomechanics demonstrates that frictional behavior is not determined solely by material properties but is greatly influenced by surface geometry, pattern orientation, and contact mechanics (Bhushan, 2013; He et al., 2008).

Studies of microtextured surfaces and anisotropic friction show that intentionally designed surface structures can regulate friction in dynamic motion. By orienting these grip structures in specific directions by their leading edge, the grip can allow its users to initially generate a higher force application while allowing a smoother release during recovery/reengaging movements. This is all made possible by biomimetic studies of snake skin and biological attachment demonstrating how grip structures can generate forward traction while minimizing resistance in other directions (Bhushan, 2012; Wolff & Gorb, 2016). Similarly, artificial traction systems in the tread of athletic footwear demonstrate a similar principle in how surface textures and patterns can control frictional movement in different directions (Hale et al., 2020).

When applied to wheelchair propulsion, these findings suggest opportunities to improve hand-rim interaction and contact. Protective adhesives with performance enhancing grip structures may increase traction during push phases while reducing resistance and abrasion during release. Integrating insights from tribology, biomimetics, and grip mechanics may lead to systems that protect an athlete's skin, hand, and joints while enhancing propulsion efficiency and overall athletic performance (see Figure 8).

Figure 8.

On hand application of the adhesive grip system called "second skin" for wheelchair athletes. Patterned protective adhesives are positioned across high-contact zones of the hand and fingers to improve traction during propulsion while reducing skin abrasion and repetitive stress.

Note: Original digital illustration created by author using Rhino8, Keyshot, and Adobe Illustrator.

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