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A Theoretical Climbing Rope

BY BRENDAN BLANCHARD

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Climbing ropes have come a long way since the days of stiff hemp cord. A modern dynamic nylon rope will catch a falling climber softly, absorb the force without placing large loads on the rest of the system, and last a long time. It's been decades since the modern kernmantle (core plus sheath) rope hit the market, and the general design hasn't changed much since. But could it be improved? What would make a rope perfect? A new study by a team from the University of Utah attempts to answer those questions, and it suggests that there is hope for softer catches in the future.

The study, published in *The Journal of Sports Engineering and Technology*, identified the most important features of an ideal climbing rope and proved on paper that such a rope could exist. The team determined the ideal rope to be one that catches a climber while applying the smallest peak load over a period of time and absorbs nearly all the energy from a fall. These two features alone mean that a rope could provide the perfect catch without any adverse effects on the climber or system.

The idea arose from Justin Boyer, a masters student in Dr. Graeme Milton's mathematical modeling class. Milton has a PhD in physics from Cornell University, as well as time spent working at NYU's prestigious Courant Institute of Mathematical Sciences. Milton currently works as a distinguished professor of mathematics at the University of Utah in Salt Lake City, where he moved in 1994 to be closer to hiking, skiing, mountain biking, and canyoneering. Though Milton doesn't climb, Boyer and graduate assistant Trevor Dick are climbers, and they were able to provide climbing knowledge when questions arose. The team was joined by Davit Harutyunyan who worked out the mathematical proof that the "ideal rope" could exist.

The study focused on the mathematical side of the ideal rope, showing that the most important behaviors—smallest peak load and max energy absorption—actually fit together. On paper, the research looks like a series of complex equations that are indecipherable to the layperson. For a simpler explanation, Milton compares the ideal rope behavior to braking in a car.

"If you brake right at the very end, you're maybe going to get whiplash," he says. "But if you apply constant braking over time, you'll avoid that." In other words, once the rope begins catching a falling climber, she would experience a consistent braking force until the rope reached its fully stretched length, then the rope would slowly retract to its normal length, instead of bouncing back up.

While no material currently exists that can achieve the team's ideal properties, they see potential in shape-memory materials, which are used to make a variety of products, from artery stents to golf clubs to helicopter blades. The study cited many potential benefits, ranging from shorter rope elongation and fall distances to decreased maximum load on the climber and all other parts of an anchor/belay system. A rope made from shape-memory wires could apply a constant braking force up to 8% elongation, and only stretch between the climber and the top carabiner. In comparison, the ropes we use today will stretch up to 15% across the entire length from belayer to climber. The shape-memory rope could brake over a much shorter distance while achieving the same peak forces on a climber, making ledge falls less likely.

Perhaps one of the biggest benefits is the durability of these new materials. Modern ropes shrink, become stiffer, and provide harder catches over time, but current shape-memory wires can undergo millions of deformations before they are susceptible to failure.

Of course, this is all theoretical. While shape-memory materials that meet some of the team's requirements exist, none are suitable for climbing applications. The material that would create the mathematically ideal climbing rope doesn't exist yet, and current materials are prohibitively expensive. For example, wire made from nitinol, a shape-memory material comprised of nickel and titanium alloy, costs $500 per meter. Shape-memory materials may also have other drawbacks, such as poor knotability, high weight, and temperature-dependent properties. One solution may be to combine shape-memory materials with current rope materials.

Milton hasn't taken the team's research to any outdoor gear manufacturers since publishing the paper, but the authors hope it draws interest from material developers. An optimal climbing rope could have other industrial applications that would warrant the research and investment needed to develop it. For example, the study suggests it could be used as a tether for dropping cargo out of a helicopter without a parachute.

"The materials you really want with these characteristics don't exist yet," he says. "But if you put something out saying, 'This is really what we'd like,' then there could be material providers that develop it."

Properties of a Theoretically Perfect Climbing Rope

- A lower maximum load on the climber and system overall
- Gradual braking, no abrupt stops that can cause injury
- The rope will return to its original shape slowly, preventing violent bouncing
- Shorter dynamic elongation, making the climber less likely to deck or hit ledges
- Increased durability, allowing millions of deformations without degrading
- Non-uniform stretching, allowing the rope to stretch only between the highest carabiner and the climber, further reducing fall distance