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An innovative hangboard design to improve finger strength in rock climbers

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Abstract

In elite rock climbing, finger strength is critical, and is directly related to performance. A hangboard, composed of sets of artificial climbing grips to hang from, is often used by climbers to improve their finger strength. While some research has studied training protocols for climbing, virtually no published research exists addressing the specific enhancement of *training equipment* to improve training effectiveness. Here we seek to show that hangboard design, especially novel features included in the Rock Prodigy Forge hangboard increases the effectiveness of hangboard training. Recently, this hangboard was developed through an iterative process leveraging modern CAD/CAM techniques. This enabled design engineers to optimize the hangboard for improved training benefit and reduced injuries. As a result, several innovative features were added to the design including: (a) equation-driven grip edge profiles, (b) drafted pockets, (c) novel grip designs, (d) improved grip geometry, and (e) improved texture, among other features. The Forge was tested by experienced climbers, and 92% assessed it as more effective than other training tools, with 91% of users able to train harder without fear of injury relative to other training methods, and 86% reporting improved climbing performance. This is a significant and unique result for the sport of climbing.

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Keywords: rock climbing; rock climbing training; hangboard; rock prodigy; rock prodigy forge

1. Introduction

In elite rock climbing, finger strength is critical, and is directly related to performance [1]-[3]. A hangboard, composed of 20+ sets of artificial climbing grips to hang from, is often used by climbers to improve their finger strength (Fig. 1). In 2014, a proven approach to hangboard training was published [4] along with a novel hangboard design, the Rock Prodigy Training Center (RPTC – Fig. 1, e) [5], which is manufactured by our research partner, Great Trango Holdings, Inc. The effectiveness of this training method and hangboard were studied, and shown to greatly enhance both finger strength and rock climbing performance [2]. After training, subjects showed a mean 32% increase in finger strength (defined as the amount of weight they are able to apply to various grips), and a mean improvement in overall climbing performance of 2.5 Yosemite Decimal System letter grades.

In this work we sought to once again improve the training effectiveness of the hangboard by applying an iterative design process utilizing modern CAD/CAM techniques – a novel approach in the climbing industry. The result is the Rock Prodigy Forge hangboard (Fig. 1, f) [6]. Varying grip designs were solid-modelled then 3D-printed. These prototypes were evaluated by elite climbers for ergonomics, specificity to rock, and training effectiveness. The computer-based development process allowed many more iterations than would typically be feasible for such a niche product. Individual grips could be produced, tested, and refined before assembling them into the complete hangboard, composed of 20+ grips. This enabled design engineers to optimize the hangboard for improved training benefit and reduced injuries. As a result, several innovative features were added to the design including: (a) equation-driven grip edge profiles, (b) drafted pockets, (c) novel grip designs, including a micro crimp with Distal Inter-phalangeal (DIP) joint guard, (d) improved grip geometry, and (e) improved texture, among other features. In this

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work, we describe these design features and demonstrate that these specific features directly improve the effectiveness of hangboard training, finger strength, and rock climbing performance.

2. Background: Finger strength training for rock climbing

2.1. Finger strength training on a hangboard

Hangboard training is an effective method for improving finger strength in climbers because it is possible to control and track many training variables such as grip type, resistance, and exercise duration [7], [8]. This is in contrast to other climbing exercises such as unstructured climbing or bouldering, wherein resistance and duration are difficult to control. Further, hangboard training is more sport-specific than other finger strength training methods, such as spring-loaded compression devices. A training device often used by climbers is the *campus board*, an inclined wall with vertical columns of edges that are climbed dynamically, without using footholds. Campusing is a plyometric exercise that is most effective for developing muscular *power* and coordination, so it is an important component of climbing training [9], [10]. However, it is not ideal for muscle *strength* training because it is less-controlled, only utilizes one grip position, and the protocols do not stimulate muscular hypertrophy [4].

Hangboard exercises consist of static two-arm “dead-hangs” (Fig. 1, a-c) in which both hands are used on the board at all times — with each hand on the same size and type of grip for a given set. The elbows and shoulders are slightly bent and the muscles of the upper arm, shoulder, and upper back should be flexed during each hang to support the athlete’s weight. The athlete does not pull-up, or otherwise vary the body position during the repetition.

Each workout entails several sets of hangs of a set duration from a premeditated sequence of climbing-grip positions. The exercise intensity can be tuned (increased or decreased) by hanging supplemental weights from the athlete’s harness (Fig. 1, b), or by attaching a weighted pulley system that assists the athlete (Fig. 1, c). This weight is also used to quantify finger strength, and has been shown to be a more reliable metric than hand dynamometers for measuring climbing-relevant finger strength [11].

Fig. 1. (a-c) Finger strength training on the RPTC hangboard and (d-f) the evolution of hangboard designs with the *Rock Prodigy Forge* (f).

2.2. Evolution of hangboard designs

Traditional hangboards (Fig. 1, d) are a single piece with a symmetric arrangement of grips. They are often designed for appearance rather than climbing-specific finger strength training. Hangboard training can lead to overuse injuries including shoulder, elbow, and wrist tendonitis, as well as injuries in the finger flexion systems (to include the flexor and extensor muscles in the forearm, flexor tendons, annular pulleys, and the interphalangeal joints in the fingers [12]). These overuse injuries may be directly caused by the traditional, single piece, symmetric hangboard design (Fig. 1, d). When training on a traditional hangboard, the athlete grabs matching pairs of grips, which are equidistant from the board’s centerline. As a result, certain grip pairs may force the athlete’s hands close together or far apart – neither of which are ergonomic positions – placing extra stress on the athlete’s joints. The RPTC, (Fig. 1, e) was the first two-piece hangboard design which eliminated this constraint. The board’s halves can be spaced at an appropriate width for the athlete and permanently mounted, or they can be attached to a movable, adjustable-width mount [13]. Early data indicates that this design is more ergonomic and less harmful [2].

The most common hangboard-related injuries are finger pad skin injuries caused by friction between the skin and grips. These may be blisters, tears, or general soreness. While minor compared to structural injuries, skin injuries are very common due to the high shear and normal stress applied to the skin. When sustained, the athlete will be unable to continue training the responsible grip position at the same intensity until the skin heals (~5 - 15 days). Therefore, skin injuries can greatly impede training.

Hangboards that were not designed for high-intensity training may have grip shapes that concentrate stress on the skin and increase the risk of skin injuries. During the development of the RPTC and continuing with the Forge, the primary design focus was creating the most effective tool for rock climbing trainin**g**. This is accomplished by maximizing ergonomics (thus, minimizing injuries) allowing athletes to train consistently at a high level of intensity, yielding the greatest gains.

3. Novel features of the Rock Prodigy Forge hangboard

The most novel aspect of the Forge hangboard might be the way it was designed. Historically, hangboards are designed by craftsman *hold shapers* who hand-carve a foam mold for later reproduction. The process is entirely spontaneous, and limited by the skill of the shaper. Instead, the Forge design process was tightly controlled through Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). This approach was also motivated by the two-piece/mirror-image design of the Forge and its predecessor [2]. During finger training, it is desirable to apply identical loads to the right and left hands simultaneously; therefore, each half of the hangboard should be a true mirror image; which is most achievable through CAD/CAM techniques.

More importantly, this computer-aided process allowed the designers to quickly create prototypes of each grip to test the grip shapes that would compose the hangboard, thus enabling rapid, low-cost iteration of each grip. Therefore, the Forge and its components were designed in SolidWorks and 3D printed for testing (Fig. 2). This is an enormous improvement in a sport that doesn't typically support large R&D expenditures; allowing each grip to be perfected at minimal cost. For example, 8+ different designs were prototyped and tested for the *Closed Crimp* grip alone, (see Fig. 3).

Fig. 2. Iterative CAD/CAM design process.

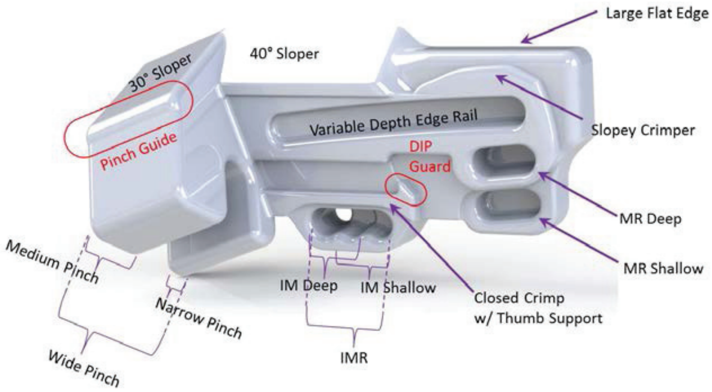

Fig. 3. Forge hangboard with grips identified.

3.1. Equation-driven grip edge profiles

During hangboard finger training, the precise shape of a grip's *lip* (the intersection of the horizontal and vertical surfaces of the grip) is absolutely critical. This lip shape determines (a) how "easy" it is to hold the grip and (b) the wear to the fingertip skin and pads (excessive skin wear can drastically limit training, and reducing wear is a primary hangboard design requirement). The

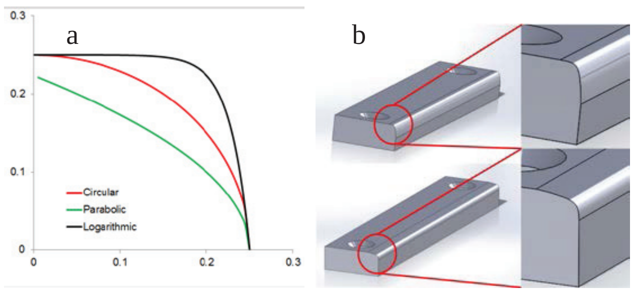

Fig. 4. (a) Comparison of various equation-driven grip lip profiles (2-D cross section). (b) – Test blocks for profile evaluation (top – logarithmic, bottom – parabolic).

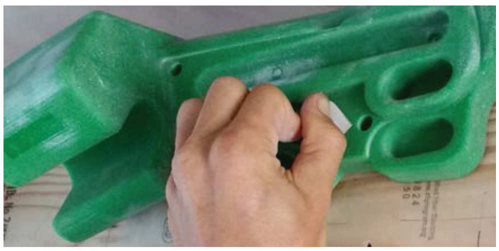

Fig. 5. The *close crimp* with the thumb wrapped over the index finger. The DIP guard supports the thumb, preventing injury.

CAD/CAM process allows tight control over lip designs, allowing improved and consistent shapes across several different grip types. The Forge's predecessor, the RPTC, was CNC milled, thus all of its lip radii are circular, due to the mill bits. With 3D printing, any shape can be specified within the resolution of the printer. In particular, parametric curves can be specified with SolidWorks' *equation-driven curve* feature, see Fig. 4 (a) for example cross section shapes. Several profiles were computer modeled, and then test blocks were drawn and 3D-printed for testing as shown in Fig. 4 (b). These were subjectively evaluated for comfort by experienced hangboard users, their assessments were compiled and discussed, and the best profile selected; a logarithmic lip shape of the form:

$$y = b - \frac{e^{a\{x-c\}}}{d} \quad (1)$$

where x and y are Cartesian coordinates and a, b, c and d are design parameters. The best lip profile was then applied to all of the pockets, and the VDER grip. The specific values for a, b, c and d are not included here because they are proprietary.

3.2. Drafted pockets

Draft is a slightly increased slope on a horizontal surface. On the Forge, all of the pockets, including the VDER are drafted at a slight angle such that the gripping surface is no longer horizontal, but rises gently from the edge of the pocket, towards the back. In climbing parlance, these grips are now essentially "slopers" because they slope towards the climber. Steep slopers are hard to hang from, but in this case the draft is subtle and reduces the joint flexion angle of the Distal Inter-Phalangeal (DIP) joint without noticeably increasing the difficulty of the grip. This provides greater skin contact surface area, especially at the back of the grip, thus increasing skin comfort and DIP joint safety.

3.3. Novel grip designs

The Forge adds several novel grips, three of which will be highlighted here. The *Micro Crimp with DIP Guard* (Fig. 3, labeled "*Closed Crimp w/ Thumb Support*") is especially innovative. The *closed crimp* grip is critical in elite rock climbing, but imparts high loads on the finger flexion pulleys, often causing severe injuries [10]. In practice, climbers will "wrap" the thumb over the index finger to improve grip strength (see Fig. 5), but this can lead to overuse injuries during training. To safely replicate this grip for training, the *DIP guard* was developed; an inclined support for the thumb that separates it from the index finger, sparing it from this added stress (Fig. 3, circled in red). This enhancement stimulates the proper physical adaptations to strengthen the climber's crimp grip without excessive wear and tear.

Another novel grip is the *slopey crimper* (Fig. 3 and Fig. 6), which was specifically requested by customers because of its pervasiveness on rock climbs. It is modeled after an existing artificial climbing hold used for training by several elite climbers. The solid modelling process allowed it to be replicated and improved, drawing on SolidWorks' *spline* function. It uses a slightly

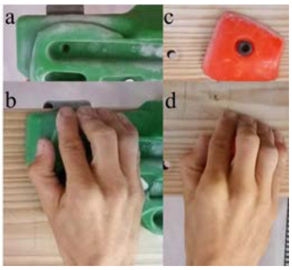

Fig. 6. (a, b) Re-designed *slopey crimper* grip (c, d) and its archetype.

Fig. 7. Adjustable hangboard mount. (a) rear view showing brackets that fit over and slide across a 2"x10" beam. (b) adjustable mount in use on the beam, from the rear, and (c) from the front.

open-hand crimp grip with an adjacent thumb surface for pinching. The design goal was to create a grip that forces each finger into the following positions: Index and Pinkie – bent at the DIP joint, Middle and Ring – bent at the Proximal Interphalangeal (PIP) joint. This design required several iterations, but the correct finger positions were achieved, as can be seen in Fig. 6.

Finally, the *pinch grip* was re-designed with one key new feature; a raised *pinch guide* (Fig. 3, circled in red) to prevent the athlete from over-reaching on the pinch. This serves as a reference point for the climber that improves training consistency.

3.4. Improved grip geometry

The Forge was designed to complement the RPTC, therefore, every grip on the Forge has distinct geometry from the RPTC, with the Forge generally having a more difficult grip for more intense training. For example, both the Forge and RPTC have *shallow 2-Finger pockets*, but the depth on these are 16mm and 19mm, respectively. The Variable Depth Edge Rail (VDER) is an innovative grip that was first introduced on the RPTC. It is an elongated pocket whose depth varies along its length, allowing the athlete to increase the difficulty of the grip by moving the hand further from the center of the hangboard (see Fig. 3). For the Forge re-design, the VDER's range, or rate of change of depth was reduced, which was another customer suggestion. The VDERs vary from 8mm – 19mm deep on the Forge and 9.5mm – 22mm deep on the RPTC (± 11mm vs ± 12.5mm). This improvement makes the depth change of the VDER less noticeable, and thus, the depth more consistent for each finger.

3.5. Improved texture

The surface texture of a hangboard is typically determined by the density of foam used to create the master for molding. For the Forge, a finer surface texture was selected which is less abrasive than that of the RPTC. The Forge texture is equivalent to"4-lbs foam" versus "8-lbs foam" for the RPTC. This change reduces the coefficient of friction between the grip surfaces and the fingers, and thus produces a more intense training experience while also reducing wear and tear on the skin (critical to effective training, as noted earlier). Furthermore, the finer texture will erode less over time, lending a more consistent training surface across the life of the board. This improves long-term training effectiveness by providing a more consistent benchmark.

3.6. Mobile hangboard mount for variable spacing and rotation

A key outcome of the 2-piece hangboard design is that it can be installed with an adjustable mount that allows the spacing between the two halves to be changed within a given workout to provide the optimal spacing for each pair of grips being trained. A method for creating an adjustable mount is described online [13] and briefly shown in Fig. 7. This feature was first introduced with the RPTC and has been very well received by customers.

Along with the spacing, it is also possible to slightly adjust the rotation of each half. This is done to improve ergonomics for certain grip types. A good example of this is the *2-finger pocket* when held by the index & middle finger pair (Fig. 8). The middle finger is longer than the index, so when they are paired, the load on each finger is unbalanced and uncomfortable. By rotating the right-hand pocket counter-clockwise and the left-hand pocket clockwise, the gripping surface for the middle finger moves further from the wrist, creating a more comfortable grip and reducing skin wear and other injury hazards. In this case, the rotation was created by simply placing shims (~2cm) under the outer mounting brackets (Fig. 7) that hold the Forge. The degree of rotation can be adjusted by changing the thickness of the shims, or placed under the inner bracket to rotate in the opposite direction (i.e., for the middle & ring finger pair).

4. Results and Discussion

The ongoing goal of this work is to improve the tools available for developing finger strength in elite rock climbers. The latest such tool, the Forge hangboard, was carefully developed through an iterative CAD/CAM process in consultation with elite climbers to optimize its training effectiveness. It was hypothesized that this process would produce a tool for finger strength training that is more effective than other methods, to include other hangboards. Furthermore, the Forge includes many novel features described above, and the relative effectiveness of each feature is also of interest. This hypothesis was evaluated by collecting performance data and subjective assessments from Forge users.

A 10-question survey was on the author's website was taken by Forge users on a voluntary and anonymous basis. Thus, the study population is not inclusive of all users, and some bias may be inherent in this survey process. Previous research indicates that most seasoned climbers experience long performance plateaus. After an initial learning period in which performance increases rapidly (~2-3 years), they tend to improve only very slowly (<1 YDS letter grade per year), if at all [2]. Therefore, any improvement in overall climbing performance shown in an experienced climber should be considered significant.

The data include both quantitative performance and subjective feedback. The Forge was released in the Fall of 2015, and therefore, user data is sparse at this time, but reflects early adopters that are generally very experienced with hangboard training, as the results show: Survey respondents reported an average of 54 months of hangboard training experience prior to using the Forge. The recommended training method prescribes 8-10 hangboard training sessions per climbing season and respondents reported having used the Forge for 12 training sessions on average. Therefore, most respondents are familiar with its features, and have at least one complete climbing season with which to evaluate its effectiveness.

Table 1. **Injury Prevention**: Study respondents' assessment of the Forge's effectiveness at **reducing injuries**. *Weighted Average* is on a scale of -2 to +2.

I am able to push myself harder on the FORGE without fear of injury than with other training methods (weight lifting, yoga, bouldering, route climbing, campusing, etc):						
50.0% Strongly Agree	40.9% Slightly Agree	9.1% Neutral	0% Slightly Disagree	0% Strongly Disagree	Weighted Average:	1.41
I am able to push myself harder on the FORGE without fear of injury than with other hangboards:						
59.1% Strongly Agree	27.3% Slightly Agree	9.1% Neutral	4.6% Slightly Disagree	0% Strongly Disagree	Weighted Average:	1.41
While using the FORGE, I experienced fewer overuse injuries (to include skin injuries) than with other training methods:						
40.9% Strongly Agree	27.3% Slightly Agree	18.2% Neutral	0% Slightly Disagree	0% Strongly Disagree	Weighted Average:	1.2
While using the FORGE, I experienced fewer overuse injuries (to include skin injuries) than with other hangboards:						
45.0% Strongly Agree	25.0% Slightly Agree	10.0% Neutral	5% Slightly Disagree	5% Strongly Disagree	Weighted Average:	1.05

A primary design goal of the Forge was to improve ergonomics in order to reduce injury potential, allowing more intense training and improved climbing performance. Therefore, users were asked to critically assess the Forge's injury potential, which is summarized in Table 1. Forge users were more confident training hard without fear of injury when compared to other *training methods* (91% agree) and other *hangboards* (86% agree). Furthermore, respondents experienced fewer overuse injuries when compared to other *training methods* (68% agree) and other *hangboards* (70% agree). Respondents were also asked to leave comments which reinforced the data, indicating fewer injuries, especially skin injuries. E.g.; *"skin is definitely holding up better," "far less skin tears and issues,"* and *"I'm able to perform more intense sets without the need for prophylactic tape."*

Study participants were also asked to report any improvement in climbing performance, and 86% of respondents indicated improvement, summarized in Table 2. Performance is further quantified by the Yosemite Decimal System (YDS) grade rating of the hardest climb the respondent was able to complete during the 4-6 weeks following training. This is compared to the respondent's previous hardest climb to calculate improvement in units of YDS letter-grades.

Of those that reported performance, respondents improved their hardest *Red Point* climb by an average of 2.0 YDS letter grades and their hardest *On Sight* climb by an average of 1.3 letter grades after only one season of training with the Forge. This is significant improvement in rock climbing as climbers typically experience long performance plateaus, and these participants tended to be experienced athletes. In the end, 86% of study participants assessed the Forge as more effective than other training methods for improving climbing performance.

Table 2. **Performance Improvement**: Study respondents' evaluation of the Forge hangboard's effectiveness at **improving climbing performance**.

Average improvement in **Red Point** climbing performance:						2.0
Average improvement in **On Sight** climbing performance:						1.3
Qualitative assessment of improved climbing performance:						
36.4% Significant Improvement	50.0% Slight Improvement	5% No Change	0% Slight Decline	0% Significant Decline	Weighted Average:	1.23
In general, the FORGE is more effective than other training methods (weight lifting, yoga, bouldering, route climbing, campusing, etc):						
66.7% Strongly Agree	23.8% Slightly Agree	4.8% Neutral	0% Slightly Disagree	0% Strongly Disagree	Weighted Average:	1.52

Due to the recent availability of the Forge, many users have not finished a complete training and climbing season, and cannot report changes in on-the-rock climbing performance, so they indicated improvement in other ways. In particular, several respondents indicated a vast improvement in confidence, especially with particular climbing grips, such as the *closed crimp*.

Finally, users were asked to assess the effectiveness of each of the novel features included in the Forge, shown in Table 3. Users overwhelmingly approve of the novel grip designs, especially the *Micro Crimp with DIP Guard* (Fig. 3), while some users are unsatisfied with the new texture.

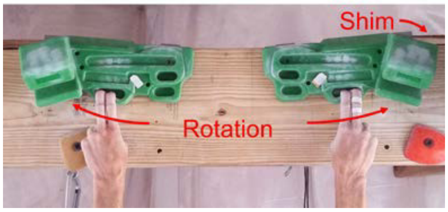

Fig. 8. Forge hangboard rotated to improve ergonomics of the index & middle 2-finger pocket grip position.

Table 3 **Assessment of Novel Features**: Study respondents' assessment of the effectiveness of novel features of the Forge hangboard; reporting the percent of respondents that assigned each rating.

	Significant Improvement	Slight Improvement	Not an Improvement
Equation driven grip edge profiles	42.9%	47.6%	4.8%
Drafted pockets	60.0%	30.0%	10.0%
Novel grip designs	86.4%	13.6%	0.0%
New hold geometry	50.0%	45.5%	0.0%
New texture	45.5%	45.5%	9.1%
Mobile mount for spacing, rotation	25.0%	50.0%	15.0%

5. Conclusion

The research goal was to develop a more effective tool for elite finger strength training by applying a modern, iterative design process. Grips and other features were designed in consultation with elite climbers, rapidly prototyped, evaluated, and re-designed to produce the highly-refined Rock Prodigy Forge hangboard. Of study participants, 92% assessed it as a more effective training tool which is less harmful and more effective at improving performance than existing training tools. As the Forge gains popularity, further research will be performed to assess its long-term effectiveness for finger strength training.

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