HandSkates: An Apparatus for Physically Intelligent Exercise

by
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ABSTRACT

Physical Intelligence refers to the ability of the human organism to smartly and precisely coordinate its internal components and interactions in its environment to solve physically complex tasks. While Physical Intelligence is a key part of physical movement, many pieces of physical fitness equipment fail to challenge or exercise the organism's internal intelligence. Therefore, the goal of this thesis is to design an apparatus that through performing a set of exercises, challenges and develops the body's physical intelligence.

Several strategies for developing an apparatus to develop physical intelligence were considered, including an underwater treadmill and an elastic method of providing resistance while running. In the end, however, the strategy developed was the HandSkate, a handheld, low-friction device intended to train core and upper-body muscles by forcing the user to balance themselves and stabilize the HandSkates while performing simple, familiar exercises.

Two concepts for the HandSkate were prototyped and tested. The first concept, the 'Boomerang' design, was prototyped from aluminum and consists of a flat, V-shaped base with a cantilevered handle. This design is small and comfortable to grip and performs well during exercises that benefit from independent hand movement. The second prototype, the 'T' design, is larger than the first but has several options for hand orientation and allows for a two-handed grip, which allows the user to perform exercises that work best with only one device. Both prototypes easily provide fine motion and provide instability, which challenges the user's physical intelligence while the user exercises. Future improvements include reducing the size of the 'T' design and manufacturing in lighter, less expensive materials.

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1. Introduction

This thesis was developed in collaboration with the Physical Intelligence seminar (SP.251) taught in Spring 2005. The goal of this class was to encourage the design and production of physical fitness equipment created with the principles of Physical Intelligence in mind.

1.1 Physical Intelligence

The concept of Physical Intelligence suggests that the body as a whole is more than just the sum of its parts. Movements that exercise the physical intelligence of the body are those that challenge the organism as a whole and introduce new ways that the body moves in relation to itself and its environment. An infant exercises his physical intelligence when learning to walk; he explores and enhances his physical relationship with his environment and improves his internal whole-body coordination.

Most exercises athletes perform to enhance physical fitness do not exercise physical intelligence. As a result, adult athletes rarely explore exercises that enhance their physical intelligence. Running for example, while an excellent cardiovascular workout, does little to enhance the organism's physical intelligence once the athlete has become proficient at that task. Similarly, weight lifting machines do not generally enhance physical intelligence – they only exercise isolated muscle groups and do not require coordination, only force. Unlike a bench-press machine, bench-pressing individual dumbbells do a better job of exercising physical intelligence because in addition to the force required, it forces the athlete to utilize hand-eye coordination and core-body strength to stabilize the dumbbells.

1.2 Goal

The goal of this thesis is to design a simple and low-cost physical fitness apparatus that develops a person's physical intelligence by accomplishing some or all of the following: introducing new movements, creating new relationships to the environment, exercising the senses, and developing core-body strength and coordination. In particular, the intention is to provide a new twist to exercises that are known to most athletes, but do not ordinarily challenge the physical intelligence of the body's system. In addition to the design and production of the physical fitness machine, a set of exercises to be used in conjunction with the apparatus that exercise the user's physical intelligence must be developed

1.3 Existing Technology

The physical fitness industry abounds with many types and variations of physical fitness equipment, but few are designed develop the user's physical intelligence. A few examples of common exercise equipment and how they develop physical intelligence are explored below.

1.3.1 Weight Lifting Equipment

One popular class of fitness equipment is weight lifting machines, an example of which is shown in Figure 1. Generally, weight lifting machines are designed to perform one or a small number of various exercises. Most machines directly control the direction of the user's movement and are limited to a small range of motion.

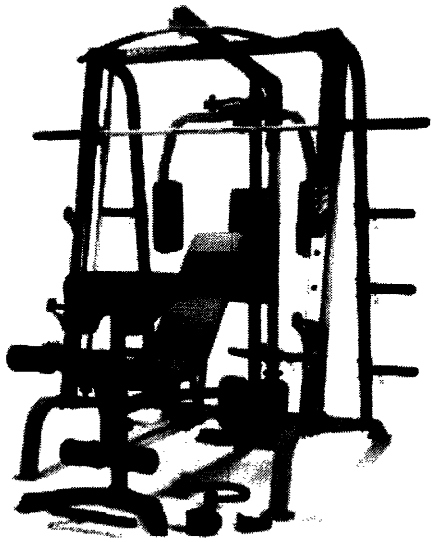


Figure 1. Example of a weight-lifting machine.

Weight lifting machines do not exercise physical intelligence because the machine directly constrains the user's motions to perform only the exercise at hand. While this attribute assures that the user always performs the correct technique, it removes many beneficial aspects from the exercise, including stabilization and hand-eye coordination. Most machines localize the benefit of the exercise to only the target muscles, thus core strength and coordination are not developed.

Simple weights, such as dumbbells, do a better job of exercising physical intelligence than do machines. Unlike machines, exercises involving free weights are not constrained to follow a given path. Instead, the user develops coordination by stabilizing the weights as he moves them along the correct path while performing the given exercise. In addition to coordination, the user also develops core body strength by exercising additional muscles that aid in the stabilization of the weights. Exercises performed with free weights do not generally challenge the user's relation with his environment (such as balance) or develop new motions (most users have become accustomed to repeating the same movements). Most exercises performed with free weights target the upper body.

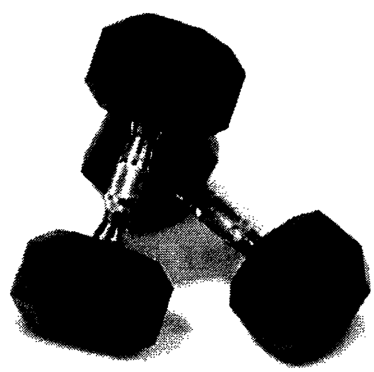


Figure 2. Dumbbell Weights.

1.3.2 Abdominal Equipment

There are currently a wide variety of abdominal exercise machines on the market. Among these is a product illustrated in US Patent Number 3,403,906, commonly known as the Ab Wheel™ (Figure 3). The user starts on his knees, gripping the handles with his hands. The user then extends forward, stretching out to a near-horizontal position before returning to the start position. The Ab Wheel™ requires the user to balance side to side, developing that aspect of physical intelligence. Unfortunately, the Ab Wheel™ only allows movement along one axis (it does not allow for linear side to side movement), thus restricting the user's motion. The Ab Slide™, US Patent Number 6,017,296, (Figure 4) is an

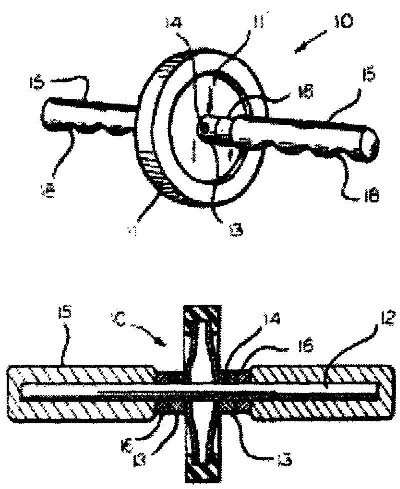


Figure 3. The Ab Wheel, US Patent 3,406,906

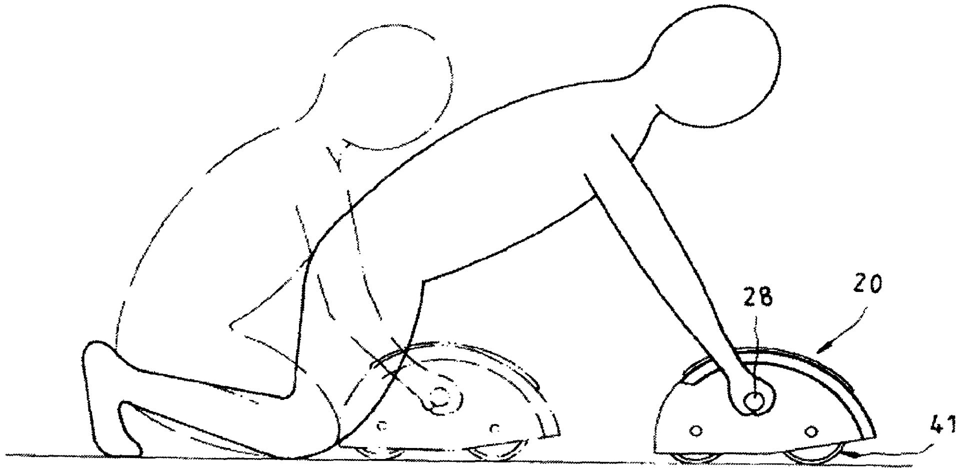


Figure 4. The Ab Slide™. This design incorporates resistance that aids the user in returning to the up position. US Patent 6,017,296

improvement on the Ab Wheel™ which incorporates incremental resistance as the user slides forward. This resistance is used to aid the user as he extends further out by minimizing the amount of torque his body must provide to remain stable. Another variation of the Ab Wheel™ is the Ab Dolly™, shown in Figure 5. The Ab Dolly™ addresses the Ab Wheel™'s problem of only functioning along one axis by employing four wheel casters to allow stable, 2-axis movement.

Figure 5. The Ab Dolly™ uses four caster wheels to allow for 2 axis

All of these designs provide the user with a new relationship to his environment by changing the way in which they interact with the floor. Unfortunately, each of these devices is designed primarily to solely work the abdominal muscles, and options to perform exercises which develop the upper body are limited with these products.

1.3.3. Equipment-less Exercises

Many common exercises, such as pushups and sit-ups do not require any equipment at all. In these, the user uses gravity to provide resistance as he lifts his body off the ground or sits up. Unfortunately, these exercises do not challenge the athlete's physical intelligence. In the pushup, for example, the hands are placed in a fixed location, therefore, efforts required for stabilization are minimal and there is little coordination necessary.

2. Strategy

Several options for developing the physical intelligence of the system were considered. Each strategy was evaluated on several points: the level to which it challenges the Physical Intelligence of the user, Simplicity, Ease of Use, Cost, Effectiveness of Related Technologies, and General Interest.

2.1 Underwater Treadmill

The first strategy considered was that of an underwater treadmill. This strategy would consist of using water to provide resistance to running (similar to Aqua Jogger concept). Unlike the Aqua Jogger, however, the runner would actually make contact with the floor, which would provide a movement more true to the actual motion of running.

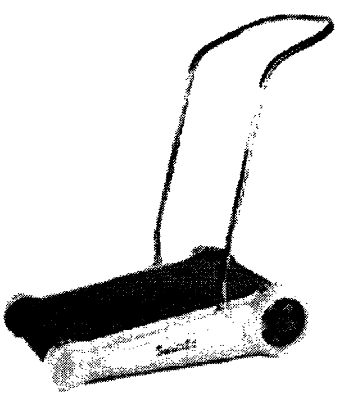


Figure 6. SwimEx's Underwater Treadmill

The underwater treadmill contributes to physical intelligence by placing a normal exercise in a new environment. Research turned up several similar products, including SwimEx's Underwater Treadmill (Figure 6). Due to the similar existing technologies, the Underwater Treadmill strategy was dismissed in favor of other designs that more acutely addressed the Physical Intelligence concept.

2.2 Resistance-Running

The second strategy considered involved providing resistance to running through an elastic or viscous device. This strategy would implement physical intelligence challenges by changing the normal relations of the body to itself during exercise. A mockup of one option for implementing this strategy is shown in Figure 7. Here, elastic bands are used to provide resistance between hands and feet, thus altering the normal relationship of hands and feet and developing muscles not normally associated with running. Other possible sources of resistance are elastic rods which would provide resistance as they bends with the leg, or the possibility of using a viscous liquid integrated into running pants that would provide resistance to movement. Existing products that provide resistance to running generally use an external anchor for elastic cords, thus limiting the length of the run to short distances. Other methods of providing resistance during running include wearing ankle or wrist weights, or wearing a harness attached to a small

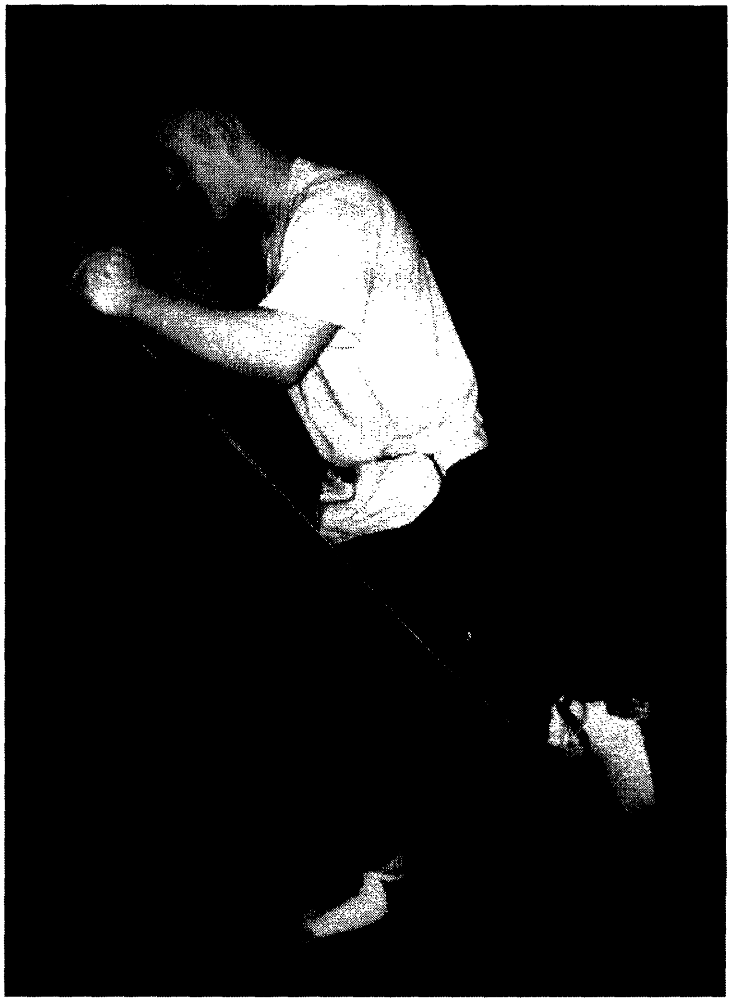


Figure 7. Providing resistance to running by use of elastic bands.

parachute, which utilizes drag to provide resistance. Concerns over the cumbersomeness of this strategy encouraged the selection of an alternate idea.

2.3 HandSkates

The third strategy consists of developing handheld, low-friction devices which develops stabilization and balance while the user performs familiar floor exercises in new ways. Inspired by the Ab Wheel, the HandSkates are designed to be used for upper body development. Incorporating a low-friction interface between the athlete and the floor

Functional Req's	**Possible Design Parameters**	**Analysis**	**Reference**	**Risk**	**Countermeasures**
Provide Low friction apparatus to force muscle stabilization	1. Ball Casters 2.Caster Wheels	1. Mockup 2. Office Chair/Caster plate	1. Omniball/ Mockup 2. Office Chairs	1. Maintenance 2. Singularities	1. Preventative Maintenance Program/Serviceable Bearings 2. Alternative solution.
Ergonomic Use	1. Flat Surface 2. Handle 3. Grippable "Lump"	1. Alignment Wrist/Hand - Control 2. Natural Motion	1. Floor Pushups 2. Weight Machines 3. Comp. Mice	Wrong Size/ Not Ergonomic Solution	Modular/ Adjustable System? Interchangeable for customization.
Safety!	1. Tether 2. Brake	1. Elastic Bungee's 2. Friction Brakes	1. Exercise Bands/Coiled Springs 2. Car/Bicycle Brakes	1. Tangles 2. Complexity to Build or Use	1. Retractable tether 2. Maybe an "Active Brake" - integrate in handle? Or Alternative Solution

Table 1. FRDPARRC table for HandSkate Strategy

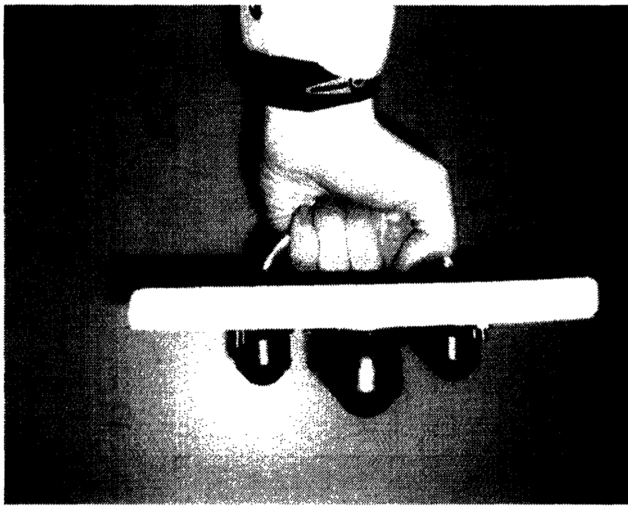
provides an interesting new relationship to the environment. The low-friction device requires the user to actively work to balance himself while performing exercises. In addition to developing balance, the HandSkates also develop muscles associated with stabilization and core-body strength. The HandSkate strategy was chosen for its contributions to Physical Intelligence as well as for the wide range of exercises possible with this type of apparatus.

Once this Strategy was selected, a FRDPARRC table (Table 1) was developed to aid in the creation of concepts for the HandSkate strategy. Three functional requirements, low friction and omni-directional use, ergonomics, and safety were identified. Several possible design parameters were identified and analyzed, along with their respective risks and possible countermeasures.

3. Concepts and Models

The goal of the HandSkate strategy was to develop a pair of handheld, low-friction devices that could be moved easily in any direction along the floor. The first concept mockup was a simple one – it consisted of a single ball caster mounted on an 8"x8" piece of wood (Figure 8). The user places his hands on the wooden platform and balances on the single ball caster.

Figure 8. Single Ball Caster Mockup



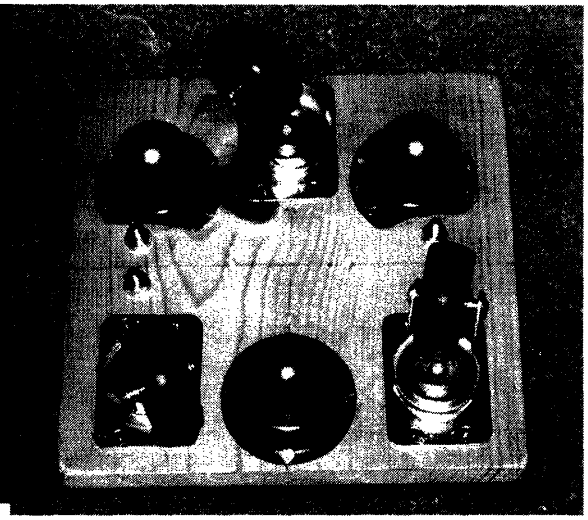


Figure 9. HandSkate mockup with handle and 3 ball casters

Figure 10. The caster wheels possess singularities and impeded fine motion.

This simple design had several key advantages. First, because of the few number of parts, the mockup was very easy and cheap to manufacture and assemble. Because it only employed a single ball caster, in addition to allowing for movement in any direction along the floor, it also required the user to stabilize the device in the tilt directions. Users commented that this design was extremely challenging to balance and recommended adding more stability as well as a handle for ergonomic considerations.

The second mockup iteration benefited from the lessons learned from the first. A handle was added, as well as two additional ball casters to provide for a stable base. The three ball casters provide stabilization in the tilt direction, while still allowing lateral movement. The handle provides an additional method of gripping the apparatus, although users complained that it was too small and not comfortable. Additionally, users reported that during some exercises, such as the fly, where the athlete stretches his arms out, the torque on the shoulder is too great to successfully complete the exercise.

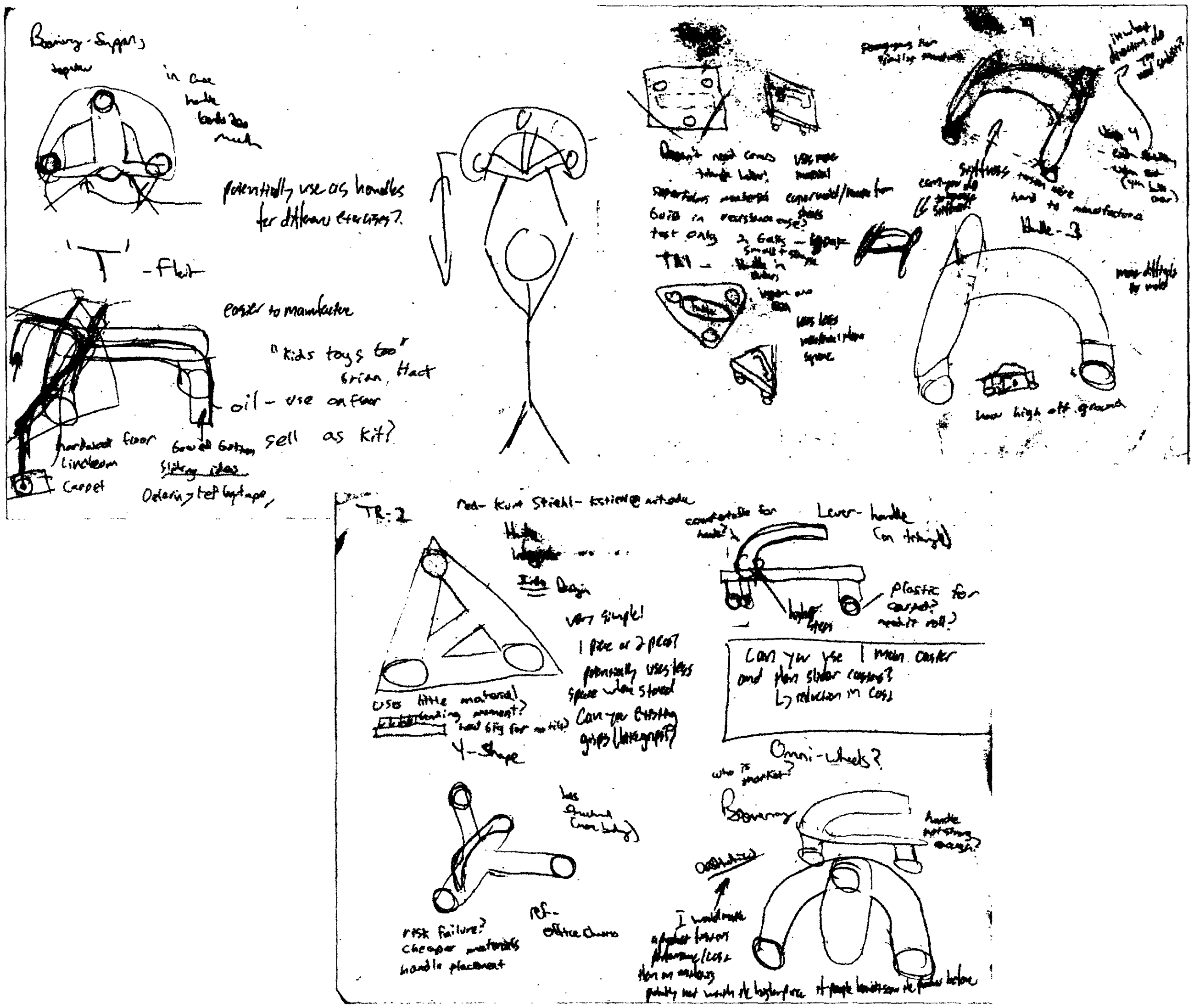


Figure 11. Sketches and Peer Reviews of Ten Design Concepts for the HandSkate

Concept	Aesthetics	Cost/Manufacturing	Ergonomics	Overall Design	Total	Comments/Ref
SQ-1	2	4	5	2	32	First Mockup
TR-1	3	5	5	4	40	SQ1 minus corners
TR-2	4	7	4	5	49	Easy to make
Handle-4	5	2	4	4	30	Extra ball transfer = expensive
Handle-3	5	5	4	6	44	Difficult to make
Y-Shape	5	4	5	3	39	Like and Office Chair base
Lever-Handle	4	4	6	5	41	
Boomerang	**7**	**4**	**5**	**7**	**47**	**more handles = better ergonomics**
Boomerang-2	7	3	7	7	47	more exercises
T-Flat	**6**	**7**	**5**	**5**		**Easy to make**
Weight	2	4	2	1		

Table 2. Pugh Chart for HandSkate Concepts

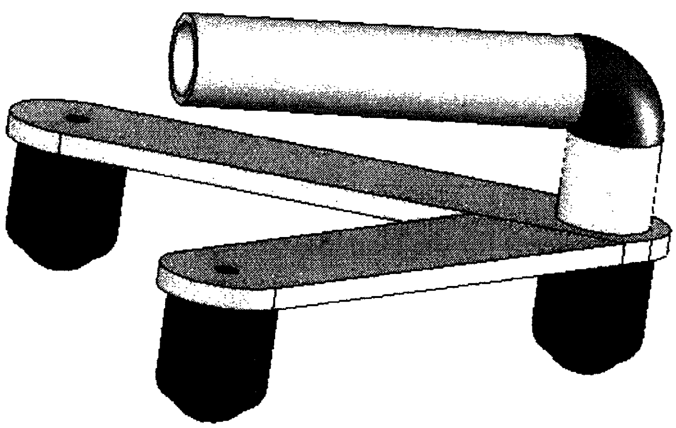


Figure 12. Solid Model of the 'Boomerang' Concept

In an attempt to reduce the cost of the apparatus, caster wheels were placed on the mockup to determine how well they functioned compared to the ball casters (Figure 10). Unfortunately, because the wheel casters each have a singularity (180 degrees from the direction of travel) the fine motion of the apparatus was impeded and performance was not as smooth as that achieved with the ball casters.

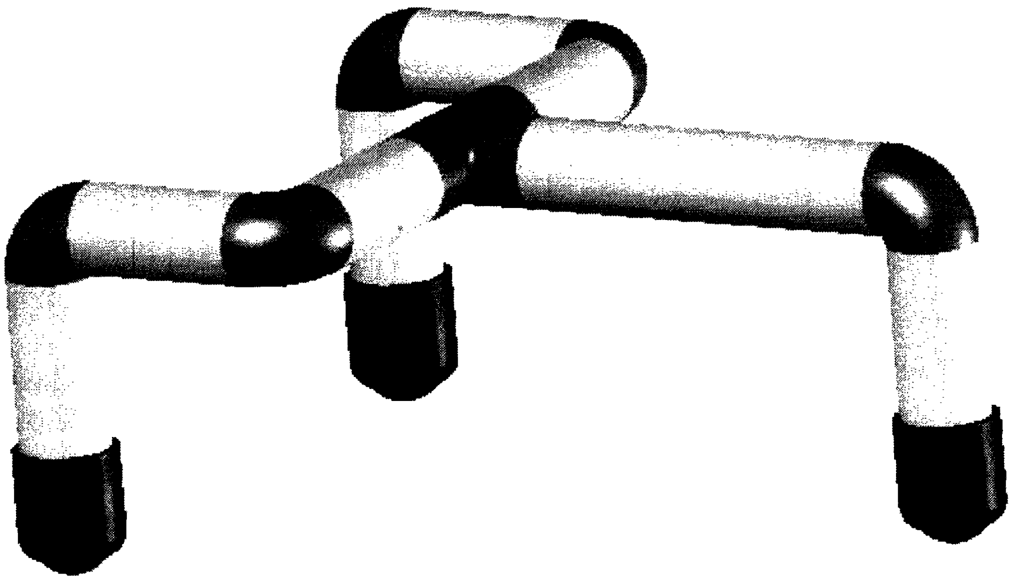


Figure 13. Solid Model of the ‘T’ variation. This design allows for a wide variation of grips and holds.

Based on the feedback compiled from the mockup, ten design concepts (Figure 11) were compiled, peer reviewed, and ranked based on Aesthetics, Cost/Manufacturing, Ergonomics, and Overall Design (Table 2). The two top concepts were selected for prototyping.

The first of the two selected design concepts for the HandSkates was the Boomerang Design, which consists of a V-shaped base and cantilevered handle. This concept was considered one of the most aesthetic of the ten design concepts and provides the user with a lightweight, low cost platform for exercise that is easy to grip. The final design for this concept was created using Solidworks; the resulting solid model is shown in Figure 12.

The second concept selected for prototyping was a variation of the ‘T’ design in which the body of the HandSkate is formed by the handle and the ball casters are fitted onto three vertical legs. This design is slightly larger than the Boomerang model, but allows for a wide variation in grips the user may use to hold the apparatus, resulting in better ergonomics. The solid model of the second concept is shown above, in Figure 13.

Maximum stress calculations were performed for each prototype. Because the most likely mode of failure is bending, the maximum elastic moment equation for bending was used to find the maximum weight of the user, assuming Aluminum 6061-T6 was the working material:

$$M_y = \sigma_y I / c \tag{1}$$

where M_y is the maximum moment, σ_y is the tensile yield strength of aluminum, I is the moment of inertia, and c is the distance of the farthest material from the elastic neutral axis. Using the appropriate values, the maximum weight that can be placed on the "Boomerang" concept is 240lbs. It is unlikely, however, that the device will fail with users up to and over 240lbs – most users will never place their entire body weight on only one device at one time (all exercises call for part of the user's body weight to be supported through his feet or knees). Similar calculations yielded a higher maximum weight for the "T" concept: 413 lbs.

4. Prototypes

Two prototypes were created, one pair of the "Boomerang" concept, and one of the "T" variation. The Boomerang concept prototype was manufactured using ¼" Aluminum plate and ¾", schedule 40 Aluminum pipe, stem-mount ball casters, and foam grips. The final assembly was welded together and stem-mount ball casters were mounted using tapped holes. The final prototype is shown in figure 14.

Figure 14. Aluminum Prototype of the 'Boomerang' concept.

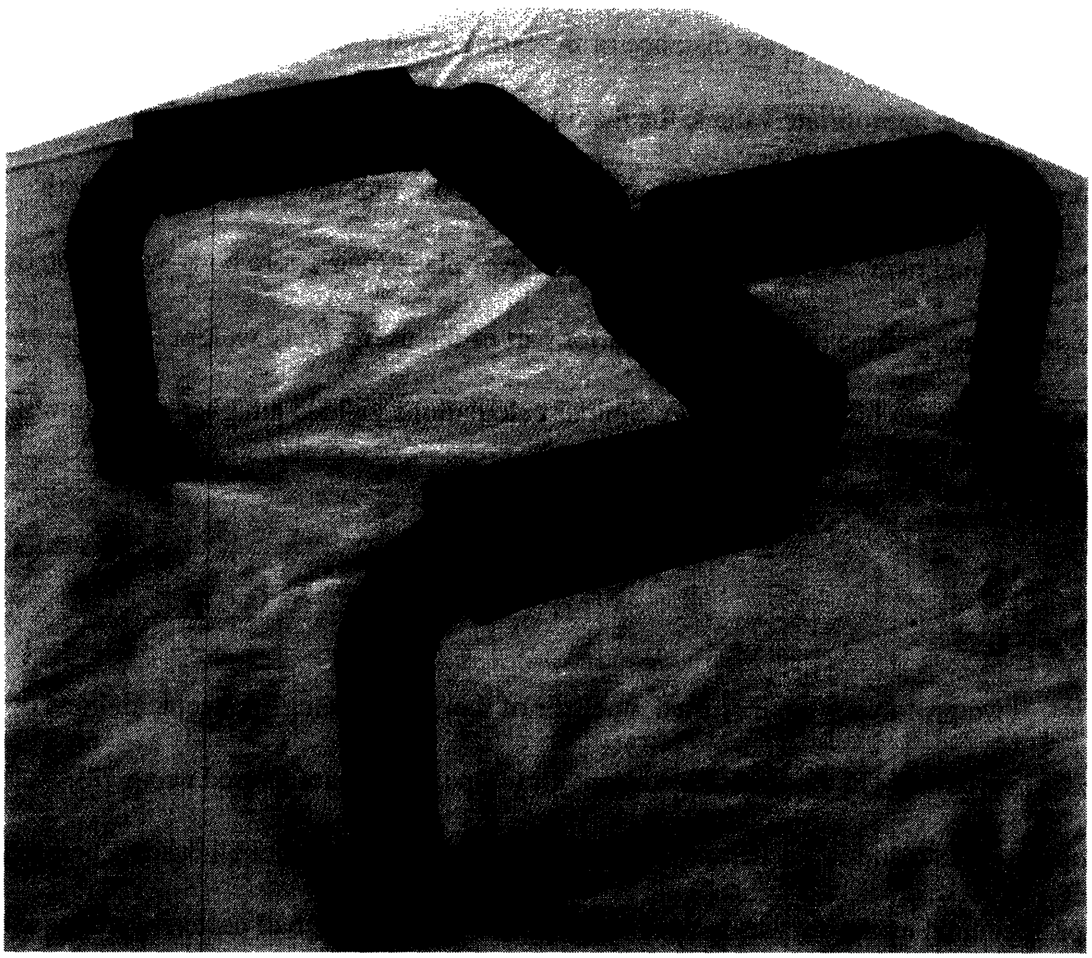
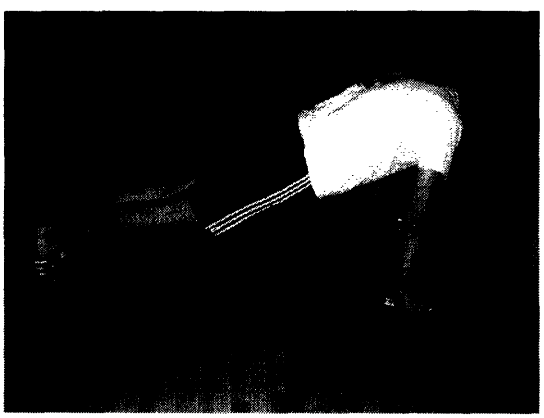


Figure 15. Prototype of 'T' concept variation. Multiple handles allow for various uses and increased ergonomics

The second concept was prototyped using Steel piping, tee and elbow bends. Each of the handles and legs were cut to length and welded together with the elbow turns and tees. Delrin was turned down to the appropriate diameter for a press fit into each of the legs, and drilled and tapped to mount the ball casters. On each prototype, vinyl foam grips were cut and mounted onto the handles for a better ergonomic feel. The final prototype is shown in Figure 15.

5. Results

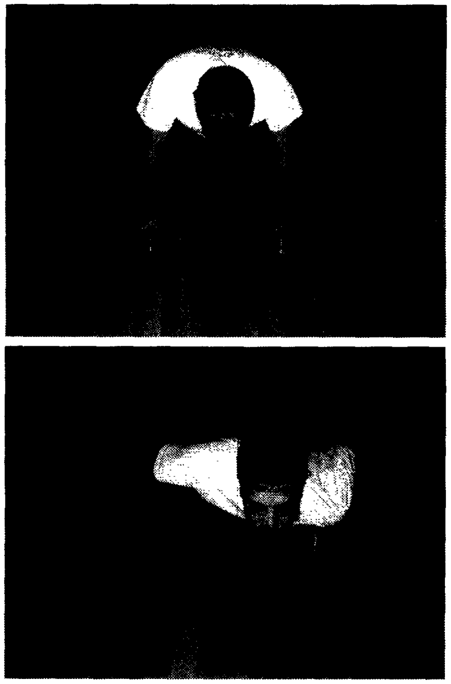
The prototypes each provided better ergonomics than did the mockups, thanks to longer and wider handles and foam grips, according to testers. Testers also noted the variety of positions that the 'T' prototype could be held in. Many testers using the boomerang pair had trouble performing exercises that involved extending their hands an arm length from their body (thus increasing the torque required from the shoulders and chest muscles). The stronger testers could lower themselves further on exercises such as the fly. Four examples of HandSkate exercises are shown in Figures 16-19.



A. Start with arms straight, HandSkates approximately shoulder width apart. Beginners may start on their knees.

B. Lower body by bending arms until upper arms are parallel with the ground. Exercise stabilizer muscles by keeping HandSkates in the same position. Repeat.

Figure 16. The HandSkate Pushup



A. Start in the Pushup Position

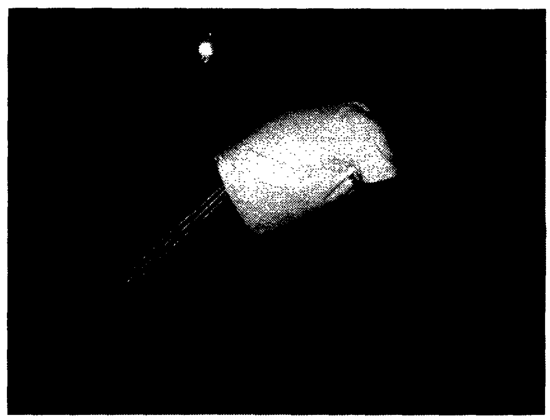
B. Bend your Right Arm while keeping your left straight and moving it to the left.

C. Return to the Up Position

D. Repeat, extending your right arm while keeping it straight.

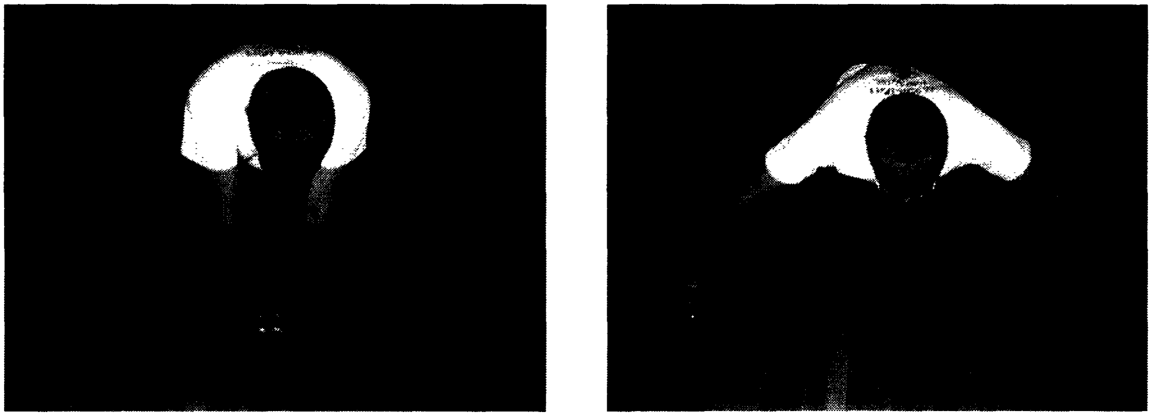
Figure 17. The HandSkate Push-Fly

A. Start on your knees with your hands together below your shoulders.



B. Slowly extend your hands forward while keeping your abs tightened. Slowly return to the Start Position.

Figure 18. The HandSkate Ab Flex



A. Start with arms straight, with your hands together underneath you. Beginners may start on their knees.

B. Lower your body by slowly extending your hands out to your sides, keeping your arms relatively straight. Slowly return the start position.

Figure 19. The HandSkate Fly.

When users placed their weight on the prototypes, they generally had to make continuous fine adjustments to balance themselves over the prototypes and keep themselves stabilized. All testers agreed that performing normal exercises such as the pushup were much more challenging due to added requirements of stability and balance.

Some users remarked that the 'T' prototype is much larger than the Boomerang counterpart and can be somewhat unwieldy when using it one-handed. Additionally, it is heavier because it is manufactured from steel rather than aluminum (the steel elbows were much less expensive to purchase for prototyping), although weight is not a major factor, because the apparatus is generally used on the floor and moved by sliding.

Some ball casters began to show wear after extended use. Dust and dirt accumulated within some ball casters, increasing the effective friction of the devices. Possible solutions to this problem include using the HandSkates only on a dedicated, clean surface, or by providing replacement casters. The HandSkate's design allows for easy replacement of of ball casters – this can easily be done by unscrewing the old ball caster, and screwing the new one into place.

6. Conclusions and Recommendations

The use of ball casters in HandSkates does successfully create a platform on which users can train the physical intelligence of their body while performing familiar exercises. In general, users find the exercises with HandSkates more challenging, and despite performing the same movements as normal, more complex. Additionally, the HandSkates allow users to perform new movements (such has the Push-Fly described in Figure 17) not normally possible with other exercise equipment.

Future improvements include utilizing an elastic band or strap to aid the user as he extends his arms outward during exercise. A simple elastic cord between two HandSkates, for example, could help provide a relatively constant, rather than increasing, load as the user performs the fly exercise. A similar concept can be utilized to aid in the performance of the Ab-Flex exercise, much like the Ab Slider does.

The 'T' concept is a bit too large to be used single-handed, but very good for double-handed use. Reducing the overall size of this concept will likely result in a more manageable apparatus to use single-handedly while still retaining its two-handed ergonomics benefits.

An additional possibility for improvement of performance is increasing the diameter of the ball casters. On smooth surfaces, the HandSkate perform smoothly, however on surfaces that contain grooves, a small, but noticeable amount of friction is added to the movement of the devices. A larger diameter ball will be better able to overtake small disturbances on the surface.

Item	Price	Qty	Total
Aluminum Pipe (per in)	$ 0.50	14	$ 6.99
1.5" Aluminum Bar (per in)	$ 0.33	30	$ 9.81
Stem-Mount Ball Casters	$ 6.60	6	$ 39.60
Foam Grip (per in)	$ 0.16	10	$ 1.58
			$ 57.98

Table 3. Bill of materials for the Boomerang Prototype

Item	Price	Qty	Total
Steel Pipe (per in)	$ 0.37	50	$ 18.33
90 deg Steel Elbow fitting	$ 5.21	10	$ 52.10
Steel Tee fitting	$ 17.19	2	$ 34.38
Ball Casters	$ 6.60	6	$ 39.60
Foam Grip	$ 0.16	40	$ 6.33
Delrin	$ 0.25	3	$ 0.74
			$ 151.48

Table 4. Bill of materials for the "T" Prototype

Each of the designs can be manufactured from cheaper materials such as plastic. Welding is clearly not the best solution for mass-production, and ideally, each base would be molded as a single piece to which the three ball casters mount. While the cost of these prototypes was expensive (approximately $58 for a pair of Boomerang concepts and $152 for a pair of 'T' concepts see Tables 3 and 4 for prototype bill of materials) most of the costs was due to the additional parts required to weld the prototypes together (such as elbow turns). Once the HandSkates are mass-produced, the material costs can easily be minimized. The most expensive component will be the ball casters, at approximately $3.60 a piece. The estimate for manufacturing a pair of HandSkates is under $25 for each design.

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