MetaHolds: A Rock Climbing Interface for the Visually Impaired

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ABSTRACT

This paper outlines the development and user evaluation of MetaHolds, a rock climbing wall designed to provide localized audio feedback for the visually impaired. MetaHolds uses head tracking technology and independent sound channels wired beneath each climbing hold that emit sound once a user's head is facing in the direction of the hold. The head orientation and position of the user is tracked in order to isolate the user's center of attention on a sample climbing wall with holds mounted at or above eye level. Two different forms of audio feedback were compared with a traditional approach involving exploration using physical contact. No significant improvement in route completion time was observed for either form of audio feedback; however, error rates and body movements were reduced while key areas of design improvement were identified for future revision.

Categories and Subject Descriptors

H.5.2 [User Interfaces]: Interaction styles; H.1.2 [User/Machine Systems]: Human factors; H.5.5 [Information Interfaces and Presentation]: Sound and Music Computing – *Methodologies and techniques*

General Terms

Design, Experimentation, Human Factors.

Keywords

Sound, voice, interaction, sport climbing, visual impairment.

1. INTRODUCTION

Indoor rock climbing is a popular sport that offers an alternative to the traditional gymnasium training regimen and an opportunity for outdoor climbers to continue training during the winter and early spring months. Indoor climbing facilities offer both top-rope and lead climbing routes with a variety of hand and foot holds mounted on reinforced plywood walls that enable climbers to traverse routes as high as 40-45 feet. Indoor climbing facilities will frequently interchange holds and create new routes every few weeks, marking holds along a single route with colored or patterned tape. Climbers will use these tape markers as an indication of their next move during a climb. In addition, experienced climbers will look further up the wall in order to determine what types of holds lie ahead and how they are oriented. This method of "route reading" allows climbers to make informed decisions as to how they should pace themselves, how they should position their body and which hand to proceed with on subsequent moves.

As one can imagine, this sport requires strength, balance, flexibility and visual acuity (or spatial resolution). For the partially blind or those with severe visual impairment, such a sport is virtually inaccessible due to the planning requirements and visual route markings. As a result, physically capable climbers with such impairments are unable to advance at the sport, due to the potential for intrusion on a neighboring route, failure due to an unforeseen hold placement and frustration due to the lack of advanced planning.

MetaHolds are proposed here as a rock climbing interface for the visually impaired. MetaHolds augment the surface of a climbing wall with speakers embedded beneath the climbing holds to emit audio as an indicator of the type of hold, the positioning of the hold or the route that it is located on. The activation of sound is controlled by the positioning of the climber and the orientation of their head, which is measured by a magnetic sensor in 3D space.

Once the direction of a climber's gaze has been determined, the area on the surface of the climbing wall that is in their direct line of sight can be calculated. With this information, the software can be informed whenever the climber's focus of attention is on a particular hold and activate the corresponding audio stream. The potential for exploration is limited only by a climber's range of head movements, as audio feedback is continually provided to interpolate between missing pieces of visual information.

In this paper, a background is provided to establish a research context for the use of auditory feedback in spatial mapping and its potential as a navigation tool for the visually impaired. The implementation of the climbing wall will be discussed in addition to the planning and execution of a user evaluation study. The results and discussion will disclose the findings of the user study while the conclusions and future work will discuss design improvements that were identified over the course of the study.

2. RELATED WORK

Previous research has attempted to draw conclusions as to the effectiveness of introducing auditory feedback in spatial mapping as an aid for the visually impaired. Previous studies have restricted either the audio feedback to a personal playback device or the spatial mapping to a single digital display. For example, Barreto et al [2] conducted an experiment to investigate both the use of 3D spatial sound and representative sound effects for the navigation of desktop icons on a display monitor. Localized auditory feedback was determined to enhance the navigation behaviors of visually impaired users during iconic search.

2.1 Hearcons and Text

Donker et al [6] recognized the limitations of the existing approaches of text-to-speech without accounting for the physical layout of web pages and developed "hearcons" that were positioned in an auditory interaction realm (3D soundscape). An auditory web browser was developed to simulate a virtual sound wall with a torch metaphor that "illuminates" only the nearest objects with a hearcon that becomes louder as the cursor is moved closer. This was deemed to more closely match the human acoustical perception system with an observation that it can be as focused as the visual perception system.

Asakawa et al [1] investigated the potential for auditory and tactile feedback as representative of a page overview with color groupings. In addition, they employed a system of sonifcation and tactilization of emphasized text by analyzing rich text information with speech. They concluded that the auditory interface was best suited to intuitive recognition while the tactile interface was more suited for concentration tasks.

2.2 Navigation Alternatives

These concepts have been extended into the physical world through processes such as echolocation, a means of localization to orient oneself in a physical environment for successful navigation and obstacle avoidance. Davies et al [4] developed a cane system that increased the preview distance for ecological interface design. Davies et al [5] also suggested ultrasound waves as a more precise medium for echolocation, which would eliminate many sources of interference in a noisy environment. This was confirmed by Pinder et al [9] in an effort to adapt ultrasound echolocation as a hybrid system for direct downconversion and human detection.

Hub et al [7] developed a sensor device for indoor navigation and object identification that could be used in much the same way as a flashlight. Results from the 3D sensor were processed and delivered to a visual impaired user in the form of a text-to-speech message. Hub et al [8] later enhanced this system to include comparison of distances between sensor data and 3D models for fixed, movable objects. In addition, object recognition of freely movable objects was developed using an algorithm that incorporated shape and color criteria. This was implemented with a heads-up-display using augmented text overlay.

2.3 Tactons

Researchers have also attempted to augment impaired visualization of spatial fields with tactile feedback mechanisms to serve as non-visual cues. Brewster and Brown [3] developed Tactons, or tactile icons, that are defined as abstract messages that take vary the frequency, amplitude and duration of tactile pulses, employing rhythm and location as distinguishing parameters. Tactons were intended to add an active component to Braille as a form of non-visual and non-verbal communication for the visually impaired.

Raisamo et al [10] extended these principles to develop a tactile memory game for children that could be adapted from a 2D visual field on a force-feedback controller to a tangible model using physical props. Communications within the memory game were managed by force feedback signals that consisted of varying strength, constancy, increase, decrease or impulse patterns.

The research efforts in exploring spatial fields by auditory or tactile cues have been limited to localization through simulated 3D sound space or impulses triggered on a personal control device. Empirical designs have not accounted for audio cues by physical layout, relative to a user's position in physical space. In addition, rhythm-based acoustic signals have not been adapted to distinguish physical objects on the basis of their physical form.

2.4 Rock Climbing

Studies on rock climbing have focused on the human kinetic aspects of the activity itself, in an effort to demonstrate the motions of the human body or the forces imposed on weight bearing cams. As an example, Schmid et al [11] demonstrate that it is possible to analyze the energy generated in the limbs of a rock climber in an effort to differentiate movements by level of expertise.

More recently, Liljedahl et al [12] designed Digiwall, an interactive climbing wall that provided a unique gaming experience for users that incorporated electronically illuminated climbing holds, sound effects and music to create a fully interactive environment. The climbing holds were designed with embedded LED's to illuminate in sequence or upon contact as part of a series of interactive games. In addition, speakers were installed around the perimeter of the climbing wall in order to provide sound effects and music during gameplay. The Digiwall has not been evaluated in a user study and the authors only acknowledge the potential for visually impaired climbers as future research.

3. IMPLEMENTATION

The design of the MetaHolds system consisted of a physical climbing space with real climbing holds, a head-mounted tracking system, an audio feedback device with a distributed speaker arrangement, audio streams to represent each of the climbing holds and tracking software to poll the tracking device and send audio streams to the correct speaker.

3.1 Climbing Holds

Real rock climbing holds were obtained from an indoor rock climbing facility and divided into the five major classes, including Pinches (Fig. 1), Crimps (Fig. 2), Slopers (Fig. 3), Pockets (Fig. 4) and Jugs (Fig. 5).

Figure 1. Pinch

Figure 2. Crimp

Figure 3. Sloper

Figure 4. Pocket

Figure 5. Jug

Each climbing hold was mounted onto a 1 foot by 1 foot plywood board, ¾ inch in thickness, same as the material used to construct indoor climbing walls. Near the base of each board, a 1 ¾ inch hole was bored for placement of a 3W/8Ohm speaker for the audio output. Each board was placed in a miniature vice grip that allowed the board to stand at 90 degrees and be spatially arranged on a bookshelf.

The test rock climbing wall was designed in pieces to allow for quick replacement of holds to provide multiple routes over the course of a single evaluation. It was necessary to frequently swap out holds in between “climbs” as there was a limit of five audio channels available and a high learning effect with respect to the placement of holds due to exploration.

Three sets of holds were assembled, in order to provide a sample set for subjects to learn and practice on, while reserving two sets for complete replacement of a set positioned on the upper shelves of the bookshelf. Although the holds between sets differed in color and size, the distinctive surface and shape characteristics made them easy to identify once users had learned the basic form and function of each hold.

3.2 Head-Mounted Tracking

The climber’s head movements were tracked using a Polhemus FASTRAK 3Space device, consisting of a base unit, a magnetic source and a remote sensor, which provided measures of position and orientation. These components were oriented to provide the least possible obstruction for subjects as they interacted with the climbing wall, while providing accurate measures of the sensor position and its orientation with respect to the climbing wall.

The magnetic source was placed seven feet high on the top of a tripod positioned on the right-hand side of the bookshelf. The source was oriented in such a way that the Y-axis for positioning was oriented along the horizontal while the X-axis was oriented along the vertical, with the left and downward directions being positive. This was necessary due to the X-axis having no negative scale (increasing positively in both directions relative to the source). The area occupied by the wall, was therefore defined by a single positive-x/positive-y quadrant. In addition, the Z-axis was defined in the outward direction perpendicular to the climbing wall itself. This was effectively the normal to the plane defined by the surface of the wall.

The remote sensor was mounted on the back of a bicycle helmet to provide users with a comfortable and unobtrusive means of wearing the sensor on the back of the head. The orientation angles of the sensor are illustrated in Figure 6, where the roll would be side-to-side movement and the elevation would be up-and-down movement in this scenario. Azimuth, or rotation about the Z-axis, made little sense due to the limited tilt of the head.

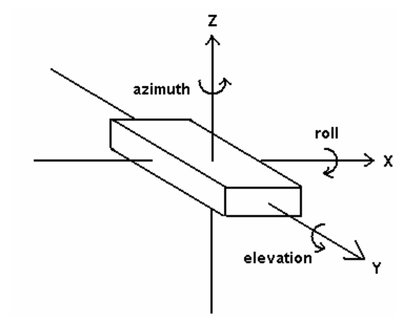

Figure 6. Sensor Rotation

If the sensor were oriented in a straight line relative to, but opposite, the normal of the plane, the following formulas provide the relative P_X and P_Y coordinates of an intersecting gaze vector with the plane, or climbing wall.

(1) if $E >= 0$, $P\_X = x - z (\text{Tan } E)$

if $E < 0$, $P\_X = x + z (\text{Tan } E)$

(2) if $R >= 0$, $P\_Y = y + z (\text{Tan } R)$

if $R < 0$, $P\_Y = y - z (\text{Tan } R)$

Where x = sensor x position, relative to source (inches)

y = sensor x position, relative to source (inches)

z = sensor x position, relative to source (inches)

E = elevation angle of the sensor (degrees)

R = roll angle of the sensor (degrees)

These formulas are effective in calculating the position in the plane that is central to a climber’s line of sight due to the independence of rotation about each axis.

3.3 Audio Feedback System

Audio feedback was provided through the use of an M-audio Fast Track Pro, an external USB sound card that provides four channel input and output for audio recording and playback. Two of the four channels were unbalanced stereo outputs, allowing division of left and right audio streams to alternate channels. The other two channels were balanced TRS outputs, which were linked and provided only a single independent output channel.

These five audio channels were routed out to a set of five speaker connections that were physically linked to speakers on each climbing hold mount and positioned on the top shelves to provide an array of sound around the climber's head. In a sense, this served as a form of simulated surround sound, in order to give climbers a sense of localization with respect to the audio output.

By creating left and right stereo separated versions of the audio streams for climber feedback, the existing stereo and TRS output channels on the Fast Track Pro could be fully exploited as independent audio channels that would experience virtually no hardware conflict by spatially separating the paired speaker channels and maintaining audio streams below a specific threshold in duration (0.5-0.6 seconds).

3.4 Audio Streams

Two different types of audio streams were developed for evaluating the effectiveness of audio feedback, including timbre-based sound effects and synthesized speech. The sound effects were developed using the Java Audio Synthesis System (JASS) and exported as PCM audio files in 16-bit WAV format sampled at 16kHz. The speech was synthesized using AT&T Naturally Speaking voices and the default female voice was chosen to pronounce the five different categories of climbing holds for this experiment.

The sound effects were designed to be indicative of the function or form of each of the climbing holds, while remaining distinct from one another for easy discrimination by test subjects. For the pinch, a sharp plucking of a string was used to represent that grip action involved; for the crimp, a wavy tone was used as a reminder of finger positioning; for the sloper, a high to low whistle was used as a reminder of the top surface area of the hold; for the jug, a "thunk" sound effect was used as a reminder of size and ease of contact; for the pocket, a dual-rebound impact sound was used to imply a cavity. These are summarized in Table 1.

Table 1. Table of Audio Streams for Effects and Speech

Hold	Effect	Speech
Pinch	Sharp Pluck	"Pinch"
Crimp	Wavy Tone	"Crimp"
Sloper	High-Low Whistle	"Sloper"
Jug	Thunk	"Jug"
Pocket	Dual Rebound Impact	"Pocket"

3.5 Tracking Software

The tracking software was written entirely in C code, having been compiled and executed under the Ubuntu 7.10 LINUX environment. The software accessed a function call library for the Polhemus FASTRAK using the 9-pin serial port interface. This allowed the tracking software to regularly poll the base unit for sensor position and orientation data, arriving in the form of an array consisting of X position, Y position, Z position, Azimuth, Elevation and Roll.

Each iteration, the software was able to store these values, calculate the X and Y intersection point of a gaze vector with the plane of the climbing wall and test specific regions of the wall where known holds were located. The position of the holds was pre-measured as these values were in inches relative to the magnetic source. The software was able to compare the calculated X and Y values with climbing hold regions along the X and Y axes of the plane, returning a positive location upon intersection.

The audio streams, or WAV files, were stored locally with the code and obtained from an external file that defined which sounds would be associated with each climbing hold position, as these holds would change from route to route. Once an intersection with one of the holds was detected, the audio stream representing that hold could be directed towards the speaker channel located at that hold position.

The software maintained an inner region of non-repetition, such that while a climber's gaze was directed at a particular hold, the audio stream would be activated only once while facing that position. Once the orientation of the head redirected the climber's gaze outside that region, the audio stream could once again be triggered upon returning. This region check was established to prevent thrashing of an audio stream, system delays and climber annoyance.

4. EVALUATION

A user study and evaluation were developed to allow test subjects to interact with the MetaHolds using traditional contact and head-tracked audio feedback methods. This would allow for a comparison of each of these methods as a substitute for visual information in a spatial mapping related task.

The purpose of the experiment was to measure the performance of a climber under the following three conditions:

i. no audio feedback provided

ii. sound effect feedback provided

iii. speech feedback provided

Under these three conditions, the performance measure would consist of a total task completion time and an error count that would be monitored over the course of several tasks, each consisting of a route or sequence of holds to be contacted. This would give test subjects a sense that they were interacting with a real climbing wall, as if they were reaching for the next logical hand hold.

The hypotheses that had been formed during the design of this study were:

H1 Shorter task times will be observed for the sound effect feedback condition than in either of the other conditions.

H2 Lower error rates will be observed in the audio feedback condition than in the no audio condition.

H3 User preference for audio feedback will correlate with task performance.

These hypotheses were investigated through the use of a within subjects experimental design that would involve repeated measures of task completion time and error rate for each of the three feedback conditions (no audio, sound effects, speech).

4.1 Subjects

Subjects were recruited from the university and consisted primarily of undergraduate and graduate students, including 7 men and 2 women in the age range of 20 to 29. Of the nine subjects, only two had previous climbing experience and four wore prescription lenses. In addition, one partially blind subject was recruited to provide a first-hand experience of what the climbing wall would be like for a visually impaired climber.

Each subject was asked to complete a pre-experiment questionnaire to establish their age range, gender, activity level, climbing experience, visual impairment and use of corrective lenses. The climbing experience would later be correlated with knowledge of hold names, while visual impairment or use of corrected lenses would later establish the method of visual occlusion and announcement of subsequent holds on a route.

4.2 Training

Each test subject was asked to complete a training session that consisted of learning the names of each of the basic climbing hold classifications, the proper handling technique for each and the sound effects that would subsequently be used in reference to each hold.

Subjects were introduced to each hand hold by name and allowed to handle the hold while learning the classification name associated with it, committing each to memory as the lesson progressed. Once the hold names were established, the proper handling technique was demonstrated for each hold and subjects were asked to replicate the technique prior to advancing to the sound effects.

Subjects were asked to handle each hold in sequence while listening to a sound effect that was associated with each type of hold through a pair of headphones. The tones were repeated twice for each user, in order for them to sufficiently make a connection between the physical form of the hold and the associated tone.

Subjects each received a quiz that tested their knowledge of each hold on the basis of name, handling technique and associated tone. The tones were played back in a random order, for which subjects were asked to demonstrate the proper handling technique on the corresponding hand hold. Once each user had achieved 100%, they were permitted to advance to the actual experiment.

4.3 Climbing Trials

The experimental trials on the MetaHold climbing wall were designed as a series of three routes that would each consist of four holds that had to be found in sequence by each subject. The length of the routes was chosen due to the availability of 5 channels and the learning effect that would result in the fifth hold being discovered through a mental process of elimination rather than through exploration.

For each route, four different climbing hold types were chosen at random and placed in a arbitrary sequence. In addition, each subject was randomly assigned to one of six possible sequences of the feedback type ordering for no sound provision, sound effect feedback and speech feedback. The random assignment of subjects into these sequences ruled out the possibility of an ordering effect from the feedback methods.

In each case, users were asked to wear a pair of fog glasses to permit the visualization of the 1’ by 1’ plywood boards but prevent the visual discrimination of climbing holds. Subjects were positioned in front of the bookshelf with the sensor helmet and given their route in pictorial form in a stack of sheets in front of them. These routes could only be traversed in sequence, one hold at a time to discourage complete discovery of the wall in the first move. As a result, subjects were more focused on finding simply the next hold by process of elimination, not mapping and memorizing the layout of all the holds.

In the case of the visually impaired subject, the fog glasses were unnecessary as they rendered the subject completely blind. In addition, the hand holds along each route were communicated verbally, as it proved to be too difficult for the subject to identify hand holds in pictorial form on a series of sheets.

Subjects were told to begin once the tracking software was executed and the timer had commenced. The time was recorded each time the user made a successful contact with the correct hold up to and including the fourth hold, at which point the timer and tracking software were stopped.

In between trials, subjects were returned to the training table and given an distraction task to perform while the MetaHold climbing wall was reconfigured for the next route. This distraction task consisted of learning knot tying techniques for both climbers and belayers (or partners at the bottom of a climb who take up slack as the climber ascends).

In addition, errors were recorded through experimenter observation and were noted each time a subject reached out for the wrong hold or applied the incorrect handling technique.

4.4 Post-Experiment Questionnaire

Upon completion of the third climbing route, subjects were returned to the training table and asked to complete a post-experiment questionnaire to establish their opinions and attitudes towards the MetaHolds concept, the different forms of audio feedback and the overall usability of the system. Statements were rated on a 5-point Likert scale from Strongly Disagree to Strongly Agree:

1. The audio feedback was useful.
2. The speech responses were clear.
3. The tonal patterns were intuitive.
4. I was able to make the associations between audio and holds.
5. The MetaHolds were responsive to my head movements.
6. Climbing was easier with audio.
7. I needed a lot of help to find the climbing holds.
8. The audio was too distracting.
9. The MetaHolds were fun to use.
10. MetaHolds are an effective climbing aid.

In addition, subjects were asked to respond to long answer questions that requested specific elements that subjects liked or disliked about the MetaHolds system in addition to general comments about the system.

5. RESULTS AND DISCUSSION

5.1 Experiment Results

The present design of the MetaHolds climbing wall demonstrated unfavorable results with respect to the first hypothesis, as no statistically significant improvement in total task time could be observed for either the sound effect (M= 55.3, SD=24.9) or speech (M=51.62, SD=30.37) feedback conditions over the silence (M=40.67, SD=15.87) condition.

A repeated measures analysis of variance using feedback as a three level within-subjects factor revealed no statistically significant effect for total task time [$F(2,8)=3.444$, $p=0.083$, partial eta squared = 0.463].

With respect to the second hypothesis, the MetaHolds climbing wall demonstrated favorable results in the sense that a statistically significant improvement in error rate was observed for either form of audio feedback, sound effects (M=0.5, SD=0.527) or speech (M=0.6, SD=1.075), over the silence (M=4.1, SD= 2.079) condition.

A repeated measures analysis of variance using feedback as a three level within-subjects factor revealed a statistically significant effect for error rate [$F(2,8)=12.084$, $p=0.004$, partial eta squared = 0.751]. The partial eta squared value indicated a very large effect size. Post hoc analysis with Bonferroni adjustment indicated that the silence condition had consistently higher errors than either the sound effect or speech feedback conditions.

In order to analyze the learning effect, a repeated measures analysis was performed for the second, third and fourth hold times as recorded upon contact by the user for each trial route under the three feedback conditions. The timing for the first hold was disregarded due to the fact that users had only just switched task contexts and required more effort to gain their spatial perspective. Results showed that in the silence condition, a statistically significant difference existed between the time required to located the second hold and the time required to locate the fourth hold [$F(2,8)=7.339$, $p=0.015$, partial eta squared = 0.647]. Post hoc analysis with Bonferroni adjustment revealed that the time to find the fourth hold (M=7.45, SD=3) was consistently lower than the time to find the second hold (M=11, SD=4.49). No statistically significant difference occurred for either the sound effect [$F(2,8)=0.970$, $p=0.42$, partial eta squared = 0.195] or speech [$F(2,8)=2.422$, $p = 0.15$, partial eta squared = 0.377] conditions.

5.2 Questionnaire Results

The post-experiment questionnaire consisted of 10 questions that were rated on a 5-point Likert scale consisting of:

1 = Strongly Disagree

2 = Disagree

3 = Neutral

4 = Agree

5 = Strongly Agree

The results of the 10 questions were averaged and are presented in Table 2.

Table 2: Post-Questionnaire Results

The audio feedback was useful	4.4
The speech responses were clear	4.5
The tonal patterns were intuitive	3.8
I was able to make the associations between the audio and climbing holds	4.3
The MetaHolds were responsive to my head movements	4.3
Climbing was easier with audio	4.3
I needed a lot of help to find the climbing holds	2.5
The audio was too distracting	2
The MetaHolds were fun to use	4.2
MetaHolds are an effective climbing aid	4.5

Notable comments on the more favorable aspects of the MetaHolds system included statements such as “Most sounds were associated well with the type of hold”, “The option for sound effect or voice may be dependent on preferred speed of movement, effects for fast and speech for slow or tired”, “It was easier to discover the type of hold by audio than by touch”.

Comments on the less favorable aspects of the MetaHolds system included statements such as “It would be better if the sound decreased as distance increased”, “It took me a while to remember which tones corresponded with each hold”, “A gradient of sound that provides a hot/cold arrangement would be more effective”.

5.3 Discussion

The task completion time did not differ in a statistically significant manner between the three conditions of silence, sound effects and speech. This can be attributed to a number of factors including the close proximity of holds, the apparent sensitivity of the tracking software with respect to climbing wall gaze intersection and the learning effects due to memorization of climbing hold layout. The real advantage behind audio feedback due to head tracking is realized with distance as routes extend 20-30 feet overhead. In this scenario there are many more holds present, most of which are out of reach. In addition, the close proximity of holds in the experiment made it difficult to isolate sounds despite their localization.

Subjects had only a few minutes to learn and recall the sound effects associated with each climbing hold, which made for an additional cognitive step in discovery mode during the tone feedback condition. Despite the fact that every single subject achieved 100% on the pre-experiment quiz, subjects did hesitate while they made a mental association between sound and hold. The three subjects with previous climbing experience were no faster at finding holds in the speech feedback condition, despite familiarity with the names.

The apparent sensitivity of the tracking software was set with generous bounds to account for differences in height (ranging from 5’2” to 6’1” in this experiment) and possible variation in the positioning of the climbing helmet on the subject’s head. Those subjects on the borderline of height or whose helmet shifted slightly forward or backward may have experienced compromised sensitivity with respect to tracking of the helmet angle relative to the climbing wall surface.

Most notably, the significant decrease in the time required to find subsequent holds in the silence condition implies that subjects were more prone to map and memorize the layout of all the holds while searching for the first few. This could be a common occurrence when the sense of touch is involved, such that more memorable associations are made between touch sensations and physical locations in space. This was not observed for either of the audio feedback conditions.

The error rate differed in a statistically significant manner such that substantially fewer errors were made in either of the audio feedback conditions compared to the silent feedback condition. This can likely be attributed to unfamiliarity with the surrounding hand holds, the lack of an initial reference point and the lack of any acknowledgement or feedback with respect to the correctness of choice and technique.

Subjects were initially lost and forced to reach out and handle each hold in a systematic manner until the correct hold could be discovered. This resulted in more guesses and a greater possibility of chance, with a higher number of initial errors that decreased as a result of a process of elimination. The lack of an initial reference point meant that users had to select a random starting point and systematically traverse the remaining holds.

Without any sort of acknowledgement of the correctness of a subject’s immediate action, subjects must assess the form of each hold by themselves, receiving verbal affirmation only when the correct hold has been discovered and handled using the prescribed technique.

The preferences discussed in the post-experiment questionnaire suggest that the tasks were deemed easier with audio feedback, the head tracking was responsive and MetaHolds are effective as a climbing aid. Subjects felt that they didn’t require a substantial amount of help, weren’t particularly distracted by the audio feedback and were split as to the intuitiveness of the sound effects that had to be memorized as part of one of the audio feedback conditions.

All subjects preferred audio feedback to silence and felt that there was a clear association between the audio and the climbing holds that each sample represented. However, subjects generally struggled while having to recall sound effect associations with the holds and expressed a preference for a hot/cold arrangement whereby the volume of audio feedback is relative to the distance that a climber’s gaze is from the climbing hold.

6. CONCLUSION AND FUTURE WORK

No statistically significant difference was observed in the task completion time between the three forms of feedback, silence, sound effects and speech. A statistically significant reduction in the number of errors was observed in either audio feedback condition over the silence condition. Although subjects expressed a strong preference for audio feedback over silence, the performance results did not correlate with this finding.

Future improvements to the system would need to include the following:

- Greater spatial separation of holds and audio channels to achieve more localized sound relative to the climber’s position,
- A hot/cold gradient architecture that would use panning and volume control to increase the volume of tones or speech as a climber’s gaze is directed progressively closer to a particular hold,
- A larger climbing wall with more holds that eliminated the possibility of mapping and memorization for subsequent experimental designs,
- The development of a virtual climbing wall to select alternate holds and layouts on the fly, forcing subjects to remain in a discovery mode of exploration.
- A training program that involves either multiple sessions or the option for climbers to program their own tones and sound effects for each climbing hold class, orientation and route.

Audio feedback as a means of interpolating missing visual information has great potential in the sport of indoor rock climbing, as demonstrated by user preference, movement/energy conservation and when scaled to a complete climbing wall extending 30-40 feet overhead.

7. ACKNOWLEDGMENTS

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