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BEHAVIOR ANALYSIS AND SPORTS CLIMBING

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Rock climbing, particularly the version known as "sport climbing," has complex response, performance and training characteristics that make it rich for behavioral analysis and intervention. The purpose of this paper is to explore the operant characteristics of sport climbing as an endeavor in its own right, but also to illustrate the potential for behavior analysis to contribute to sport psychology in general. Accordingly we will: (a) describe sport climbing, emphasizing its behavioral demands and consensus training procedures, (b) review conventional climbing literature (e.g., training books) and research on variables affecting performance in sport climbing, and (c) describe, with supportive data, how behavioral principles and procedures could be applied conceptually to sport climbing, and (d) to suggest opportunities for operant research and practice.

Keywords: rock climbing, behavior analysis, sports performance

Sport climbing is a highly athletic form of rock climbing in which the climber performs complex gymnastic moves on overhanging or seemingly blank vertical rock faces. The venue may be outdoors on natural cliffs, indoors on artificial climbing gym walls, or, as is most often the case, a combination of both. Climbing gyms afford climbers a multi-faceted training environment in which to prepare for outdoor ascents (Hörst, 2007). They also play host to an international network of climbing competitions. In the past two decades, the popularity of sport climbing and its cousin "bouldering" have grown dramatically, resulting in busier cliffs and boulder fields, an increased number of indoor climbing gyms, the continued growth of national and international competitions and the formal recognition of sport climbing as an Olympic event.

The ultimate goal in sport climbing is a *redpoint* ascent, a fluid and graceful ascent of a difficult climb using hands and feet alone. Ropes, bolt anchors and a competent partner to feed and hold the rope ("belay") are employed as safety precautions, but only to catch the climber in the event of a fall. In a redpoint ascent, the rope is never weighted. The process of accomplishing such an ascent is painstaking. Many hours, or even days, are devoted to acquiring and rehearsing difficult individual moves on climbs which usually cannot be completed on the climber's first attempt. Through repeated practice, individual moves and short sequences are linked and the climber ultimately is able to complete a fluent ascent, free of falls. Generally speaking, sport climbing is an *open* sport: each section of rock face a climber encounters for the first time is different from any other she or he has seen, although important similarities also exist. Because every climb is different, the rock athlete is challenged to quickly and efficiently generalize from a set of core physical techniques (response topographies) to meet the requirements of the climb. Arguably, once a climber selects a difficult climb as a long-term project, sport climbing becomes a *closed*

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sport; the task at hand is to learn and link movement in a choreographed routine, much like a floor routine in gymnastics (Wolko, Hrycaiko & Martin, 1993). The interplay of these open to closed-sport characteristics of sport climbing is what appeals to most sport climbers.

Systematic training approaches have contributed to large advances in difficulty in sport climbing in recent years. It may also be true that the far greater number of young people trying the sport indoors has "selected" for individuals who are the most genetically well prepared for the sport. Interest in the relative contributions of innate ability and dedicated training in the development of expertise in general has led K. Anders Ericsson to elaborate a theory of "deliberate practice" that is highly compatible with a behavioral approach to skill development (Ericsson, Krampe, and Tesch-Romer, 1993; Ericsson, 2007). Elements of deliberate practice applied to sport, which most certainly apply to sport climbing, include: (a) objective assessment of the athlete's physical, cognitive and emotional strengths and weaknesses, to learn where best to intervene; (b) program planning, accompanied by formal long and short-term goal setting; (c) systematic practice for acquisition of specific motor behaviors (response topographies); (d) repeated practice of new response topographies to build requisite fluency; (e) stepwise methods for linking complex sequences of moves (e.g., backward and forward chaining); (f) the use of carefully-designed macro- and micro-cycles of training to optimize physiological adaptation and progress, including training "periodization;" and (e) precise self-management of time, goals and motivation. Advice on deliberate training for climbing has been conveyed in several sophisticated books written by highly accomplished, or elite, climbers, most notably Hörst (2003, 2007). Controlled research on climbing has been limited, but a few studies have focused on the biomechanics of climbing movement, using sophisticated electronic measurement and transduction technology. The opportunities for operant research are clear and present.

Sport climbing techniques and training regimens are far more systematic than the rock climbing and mountaineering approaches of old. As noted, a handful of elite and academically oriented climbers have contributed to training wisdom in important ways. They have integrated developments in exercise and sport science with their own training and climbing experiences to produce sophisticated training programs (e.g., Hörst, 2003, 2007; Goddard & Neumann, 1994; Sagar, 2001). Procedures best suited to the physical form requirements of sport climbing address: (a) systematic approaches to learning biomechanically efficient but surprisingly counterintuitive moves (response classes) needed to complete difficult sections of multi-section climbs; (b) repeated and deliberate practice of these novel response classes, in order to build fluency; and (c) practice at linking sequences of moves, i.e., establishing the stimulus-response chains that present themselves on sport climbs. One such response class is the "twist-lock," a move in which the climber is better able to grasp and use a small handhold on overhanging rock by back-stepping the opposite foot on a foothold and then quickly turning that same leg and hip into the rock. This move yields tremendous biomechanical advantage over the more typical straight-on orientation, yet it is a move that most climbers do not discover on their own.

Training approaches have not been limited to physical skill acquisition. Hörst (2003, 2007) elaborated on the assessment and broad-based management of motivation, fear, physiological preparation (anaerobic and aerobic endurance, strength, power, and flexibility requirements) and nutritional aspects of climbing. This expanded list of training requirements calls on the use of operant and cognitive-behavioral procedures to accomplish priority setting, time management, goal-setting (stimulus control and establishing operations), systematic desensitization (to become comfortable with safe falling), positive self-evaluation and self-talk (verbal behavior) and continual measurement and monitoring of progress.

What is the current knowledge base in sport climbing, and how has it been developed? The following section describes conventional, experience-based wisdom and the limited empirical research that has contributed to the "working" knowledge base.

CONVENTIONAL WISDOM AND RESEARCH

Conventional Wisdom

One source of sport climbing knowledge comes from the reports of highly accomplished climbers, those who climb at the highest levels, establishing extremely difficult new routes on natural rock, or placing in the top ranks in national or international competitions. Elite climbers typically have achieved that status through ten or more years of intensive and goal-directed practice - the type of deliberate practice described in the seminal paper by Ericsson et al (1993). Consider two examples of conventional wisdom: (a) identification of a repertoire of response classes that all sport climbers will need to acquire, and (b) tactics involved in linking (chaining) sections of a difficult climb to produce a well-orchestrated final ascent. Note that we now turn to using operant terminology to more accurately describe the elite climbers' non-technical descriptions.

Advanced-level sport climbing requires the climber to have a broad repertoire of moves. Although each new expanse of rock to be ascended presents a different set of behavioral requirements, there are still reasonably discrete classes of moves and distinctive stimulus conditions, i.e., physical characteristic of the rock face such as its angle, the orientation and size of handholds and footholds, etc. The best climbers will have a well-practiced repertoire of many classes of moves and will apply the most efficient moves (and do them quickly) under the presenting stimulus conditions. One elite climber, Francois Legrand, attributes his success to the fact that he has developed an especially broad response repertoire and has learned to quickly match moves to conditions that occur on a novel climb (Perlman, 1995). Legrand refers to response repertoires as "families of moves," and his description of the different families is fairly consonant with a behavior analyst's description of response classes. For example, one class of moves is called "underclings," which can be defined as grasping the underside of a down-facing hold with one or both hands and pulling up and out on the hold in order to advance. Legrand points out that the exact form of the undercling may vary and shift considerably, depending, for example, on the positioning of one's feet on existing footholds. Thus, there exists a response class of undercling moves, and top climbers will have practiced the many variations of such moves so they can fluently adapt their behavior to suit different rock conditions. In behavior analysis terms, generalization among the members of a response class is critical to expert performance. There are probably 10 to 15 major response classes used in sport climbing, the twist-lock described earlier being another.

Another aspect of climbing involves the seamless sequencing of individual moves, especially those required on the most difficult sections of a climb, to complete a redpoint ascent. Once all of the individual moves on a climb have been mastered (by hanging on the rope at each section to rest and repeatedly attempting the moves until they are fully acquired) the climber still has to link the moves together. This linking of individual sections is easier said than done: the climber must posess the endurance to complete the entire sequence without rests, and tricky transitions between

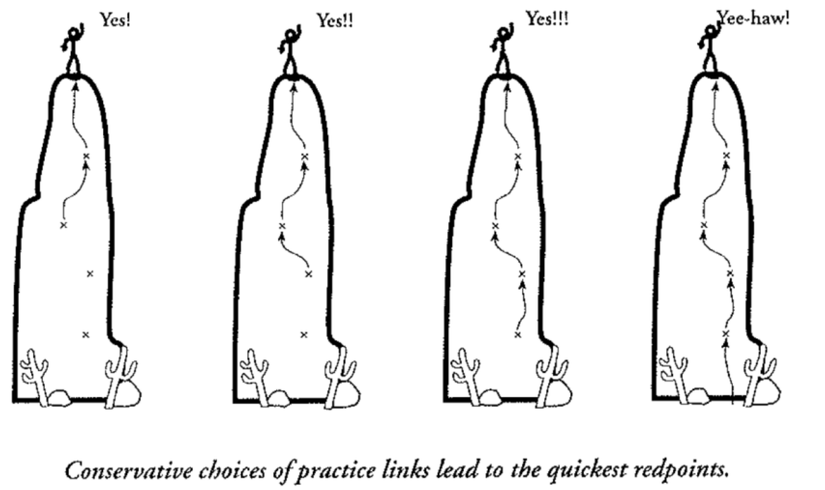

Figure 1. Illustration of backward chaining applied to a sport climber's preparation for a difficult redpoint ascent. Reprinted with permission from Stackpole Press.

moves must be well rehearsed. One highly recommended procedure for systematically linking sections of a climb together, illustrated in Figure 1 (from Goddard & Neumann, 1994) essentially is backward chaining. The procedure recommends linking the last sections of the climb first and then working backward to add the other sections. What is the authors' rationale for working in this order? They suggest that the repeated rewarding experience of reaching the top will better motivate the climber to complete the strenuous rehearsal requirement. In behavioral terms, the climber maximizes reinforcement during practice by repeatedly succeeding on the final sequences.

Research

Controlled research on operant and cognitive-behavioral procedures has been applied to sports such as swimming (Hazen, Johnstone, Martin, & Srikameswaran, 1990), baseball (Heward, 1978), football (Komaki, & Barnett, 1977), and others (see Martin, 2007, and Martin & Tkachuk, 2000 for comprehensive reviews of behavioral sport psychology research). However, research on sport climbing has been sparse. The authors found three articles in the scientific literature that, while not operant in nature, have implications for a behavior analysis of sport climbing. Two of the most interesting investigated aspects of motor behavior in sport climbing. Cordier, France, Bolon and Pailhous (1993) used geometric statistics to quantify and compare the searching (route finding) behaviors of novice versus expert climbers. As a function of having more experience, expert climbers were hypothesized to be more successful than novice climbers at analyzing novel situations and performing moves in a more efficient manner. In other words, their response repertoires would be expected to be more fully developed and integrated. Climbers were fitted at the waist with a light-emitting diode, the movement of which was recorded on videotape and then processed by a computer application, resulting in digitized recordings of movement trajectories and quantification of entropy (a measure of the complexity of the climbers' trajectories).

Climbers were asked to complete ten climbing trials on a novel route with one-minute breaks separating each trial. Comparisons of the time-series entropy data for each group collected over ten trials showed that experts climbed far more efficiently. From an operant perspective, the measurement technology used in this study is appealing. By transducing behavior (Johnston & Pennypacker, 1993), the less direct and reliable option of experimenter observation and recording is obviated.

Nougier, Orliaguet, and Martin (1993) investigated modifications in climbers' manual reaching (for a handhold) as a function of starting posture (easy versus difficult), the nature of the hold to be grasped (simple versus complex), and the sequence of the movement (right-hand movements alone or before or after left-hand movements). The authors' main hypothesis was that a difficult starting posture should result in a decrease in the duration of the reach. Five expert climbers each performed 120 trials of reaching and grasping on an artificial climbing wall. Each subject performed under each of the three condition manipulations - starting posture, hold size (nature), and sequence. Infrared emitting diodes placed on the right hand allowed for the precise measurement of the form and speed of hand movement. Results indicated shorter movement durations for the more difficult posture, regardless of the size of the hold or the sequence, and longer-duration times for the easier posture. Finer grained analysis of the course of acceleration of hand movements under both conditions suggested to the authors that typical cognitive "online controls" were suppressed by the state of disequilibrium experienced in the more difficult posture.

A BEHAIVOR ANALYSIS OF SPORT CLIMBING

The premise of this paper is that behavior analysis has the potential to contribute to the understanding, assessment and enhancement of sport climbing performance. In the following section: (a) behavioral principles (reinforcement and stimulus control) and establishing operations are applied conceptually to describe sport climbing performance; (b) common stimulus and response classes in sport climbing are described; (c) the role of stimulus and response generalization in sport climbing is explained; (d) critical dimensions of climbing response classes are illustrated; and (e) behavioral procedures that could further improve climbing training and performance are described.

Reinforcement, Stimulus Control, and Establishing Operations

Positive and negative reinforcement play important roles in sport climbing. Most sport climbers set goals for themselves (usually to redpoint a challenging climb) which establishes both interim accomplishments, such as mastering individual moves or linking short sequences, and the terminal accomplishment of completing the redpoint ascent, as powerful natural reinforcers. The social encouragement that typically accompanies these stepwise and terminal accomplishments supplements these reinforcers. Negative reinforcement also comes into play. A climber may make one last determined attempt to redpoint a climb at the end of the day to avoid having to return to the climb on another day. Or, one may climb more carefully through a section to avoid a potentially harmful fall.

Stimulus control is another important principle in sport climbing. Correct (immediate and accurate) performance of difficult moves occurs when the climber's motor behavior comes under tight stimulus control of critical features of the rock face - crucial handholds, footholds, or cracks. As might be expected, stimulus control is established through repeated successful practice of individual moves, once the climber has acquired them. Stimulus control operates as sequences of moves are linked: stimuli associated with the completion of one move, such as the sight of the next rock features, the feel of the footholds and handholds one has reached, and even subtle proprioceptive feedback associated with body position, serve the dual stimulus function of reinforcing the completion of the previous move and occasioning performance of the next difficult move.

The type of reinforcement and stimulus control relations described above can be disrupted or improved by prior events that function as establishing operations. If the climber is fatigued from inadequate rest or recovery, or perhaps distracted by pressing personal problems, he or she might not attend and respond as effectively to the critical stimuli on a climb. Conversely, the climber who is well-rested and who has practiced visualizing a successful ascent might experience maximum performance. For the more competitive climber, the magnitude of reinforcement for progress on a climb might be significantly diminished if another climber succeeds first at the redpoint ascent. Conversely reinforcement might be increased if the competitor fails on a previous attempt, thus opening a competitive "door." Concurrent events might also affect performance. The presence of a crowd of onlookers on a busy day, extreme heat and humidity or cold, or a new partner might adversely affect performance. Again, the flip side is that an absence of onlookers, optimal temperature and humidity, and a familiar partner, might enhance performance.

Stimulus and Response Classes

Stimulus and response generalization are critical in sport climbing. For experienced climbers, the physical features of rock faces fall into distinct stimulus classes, each calling for a particular class of response. Cracks ranging in width from 1½" to 3" occasion the response class of hand jamming (fitting in and then wedging the hand into a crack), whereas ½" to 1½" cracks occasion finger jamming. A long reach between two good handholds on a severely overhanging wall might occasion a static twist lock move. A reach that cannot be made statically because the handholds are too far apart calls for a dynamic move - a controlled lunge from one handhold to the next. The more experiences a climber has had matching responses to different types of rock features, the more organized the various stimulus classes become.

Just as features of the rock fall into stimulus classes, different types of movements form response classes. Using an example from above, the hand position used to jam in a 1½" crack is somewhat different than the hand jam in a 3"crack, yet both fall into the response class of hand jams. Similarly, the propelling dynamic force needed to stab a handhold three feet beyond one's maximum static reach will be greater than if the handhold is only 6" out of reach. Yet both moves would still be considered to be in the response class of dynamic movement.

Stimulus and Response Generalization

It should be evident at this point that although relatively distinct stimulus and response classes exist in rock climbing, stimulus generalization and response generalization are critically important. Because the physical features of each piece of rock vary, a range of variations within a stimulus class must occasion the correct response classes (stimulus generalization). In addition, slight but critical adaptations to responses within a response class must also occur to accommodate the different physical features of the rock. Thus response generalization is another important component in building a climbing repertoire, and variations must be deliberately trained.

Critical Behavioral Dimensions

A host of behavioral dimensions are important in sport climbing. Because climbers need to employ the most biomechanically advantageous (e.g., strength-conserving) forms of movement on the rock, specifying the topography of response classes is very helpful in training and practice, for example, keeping the hips close to the rock when moving up a severe overhang (e.g., the twist lock) will

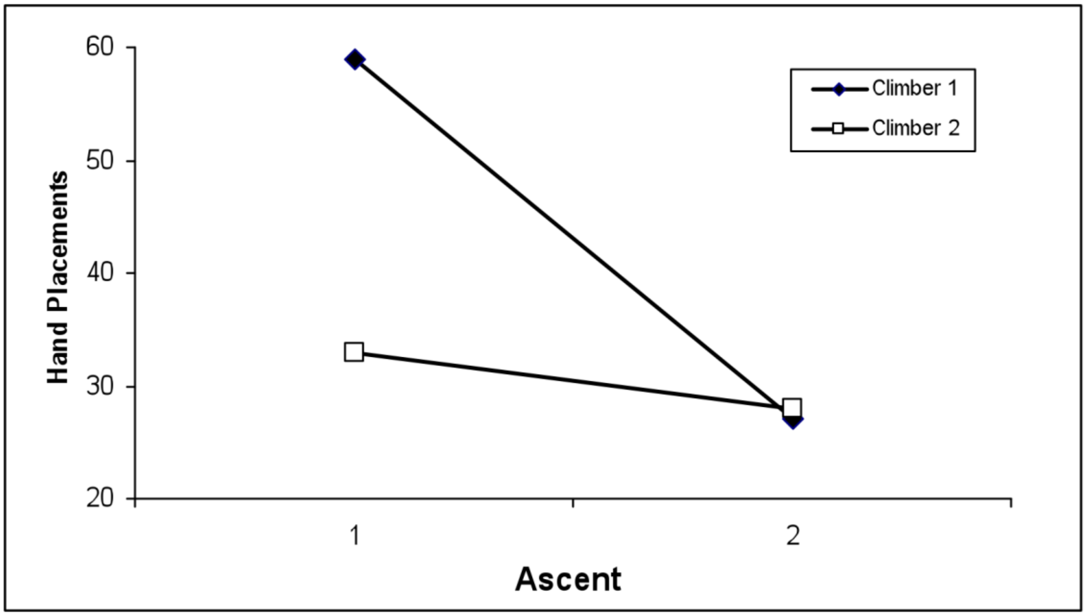

Figure 2. Hand placements of first and second ascents of a difficult route by a less experienced climber (Climber 1) and a more experienced climber (Climber 2).

better position one's bodyweight over the feet and legs and off the weaker forearm and arm muscles. Duration is another critical dimension. Generally speaking, the longer a climber spends on a climb, the more fatigued she will become. Faster ascents, as long as the moves are performed in good form, will use less energy than slower ascents. In many instances, frequency is an important dimension. An experienced climber can usually be distinguished from a novice climber by observing the number of hand placements used on a climb: the experienced climber will usually pick the most advantageous handholds the first time while the novice will need to seek out and test more holds before committing to moves. Accuracy also distinguishes expert from novice climbers. Experts will place their hands or feet precisely on handholds and footholds, whereas a novice might be more apt to over or under reach for holds, necessitating recovery from the inefficient effort. Finally, intensity can prove important. Expert climbers use the least force necessary to grasp a hold. "Overgripping" a hold, out of fear, inexperience or both, can waste energy and result in premature failure.

Figures 2 and 3 illustrate the use of two behavioral dimensions to measure sport climbing performance frequency and duration. Two climbers were videotaped climbing a severely overhanging and difficult (5.11c) climb on natural rock. Performance evaluations on overhanging rock are especially informative when comparing expert and less-than-expert climbers, because an inefficient hand or foot move on such terrain can cause the climber to torque ("barndoor" in climbing terms) outward and potentially lose purchase. Each climber completed the redpoint on their second attempt; the first attempt for each involved in a fall and a brief rest on the rope. Climber 2 had over 20 years of experience, mostly on natural rock. Climber 1 had been climbing for less than two years, although he had trained extensively over that period in an indoor climbing gym and was the physically stronger of the two climbers. Data were

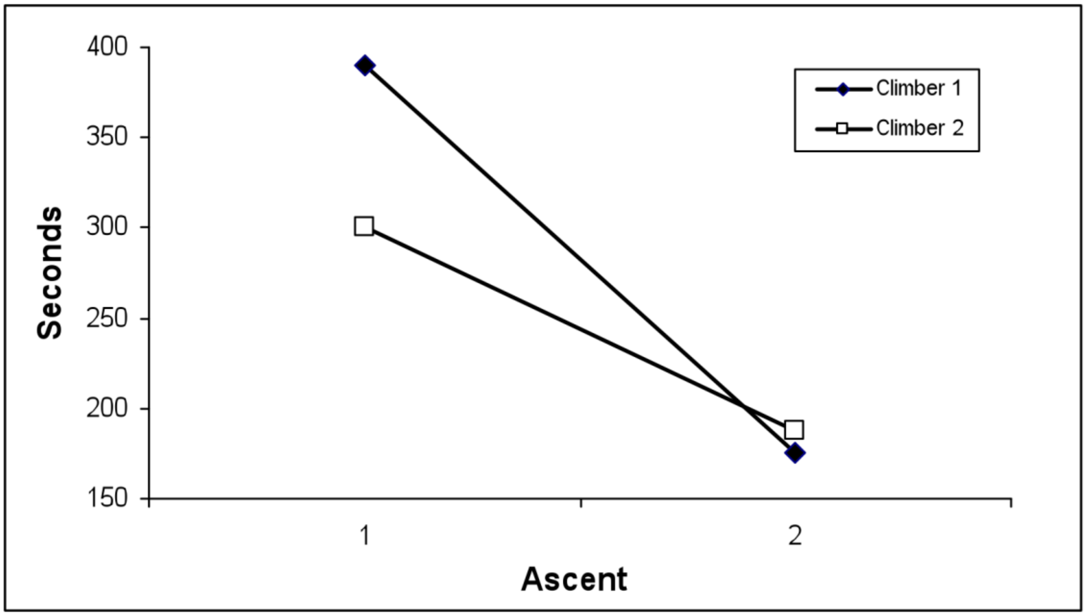

Figure 3. Durations of first and second ascents of a difficult route by a less experienced climber (Climber 1) and a more experienced climber (Climber 2).

recorded directly from videotapes of the fours ascents.

As the Cordier et al (1993) study suggests, the more experienced climber should search less and grasp fewer holds than a less experienced climber during an initial ascent. It might also be expected that a more experienced climber (Climber 2) would require less time on the rock to succeed in making moves. Figure 2 depicts the number of hand placements (one hand grasps a hold and maintains that grasp for 2 sec or more) made by each climber on their first (practice) and second (redpoint) ascents. Note that Climber 1, the less experienced climber, used almost twice as many hand placements as Climber 2 on the first ascent. On the second ascent, the climbers were remarkably similar in the number of hand placements they used; Climber 1 adapted quickly.

Figure 3 shows durations for the first and second ascents of each climber. Again, Climber 1 took longer to complete the first ascent, but both climbers took approximately the same time to complete their redpoint ascents. These data are only meant to be illustrative of the notion that measuring the dimensions of frequency and duration may help distinguish experienced from less-experienced climbers, and may provide a useful index of progress for aspiring climbers.

Behavior Analysis Procedures and Sport Climbing

Formal behavior analytic procedures appear particularly well suited to sport climbing. Self-managed shaping could help a climber to master difficult technical moves during the acquisition phase of a redpoint effort when first attempting a climb. For example, a move involving awkward body positioning could first be approximated, with closer approximations being added as the climber's body adjusts to the novel orientation. This seems to happen naturally when one watches climbers working out hard moves in a gym, but atten-

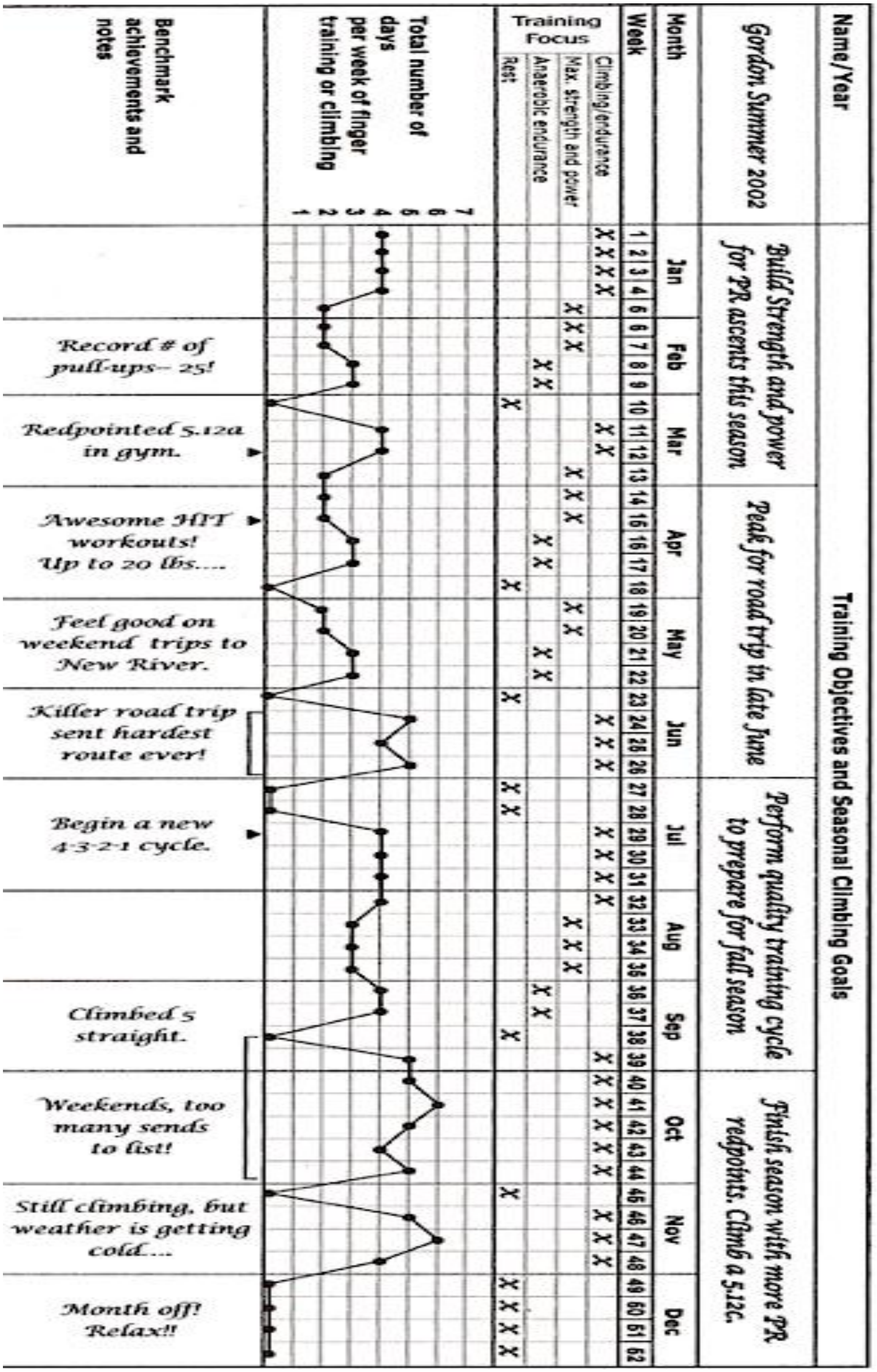

Figure 4: Training objectives and seasonal climbing goals, from *Training for Climbing* (Hörst, 2003)

tion to the size of approximations might help a climber progress faster. Alternatively, a little assistance in the form of a slight upward pull on the rope might at first help a climber complete a move. The assistance could then be gradually faded until the climber is performing the move independently.

Forward and backward chaining procedures are also well suited to sport climbing, especially at the linking stage of an ascent. The Goddard and Neumann (1994) example described earlier suggests that backward chaining might be more motivating because the climber gets to sample the highly reinforcing consequence of reaching the top of the route. In addition, the greater amount of practice on the last sections that would occur with backward versus forward chaining might work to climber's advantage on a redpoint attempt: fatigued at the end of the ascent, the climber might profit from the conditioned reinforcement and stimulus control operations that were established through repeated practice. In other words, the climber might find it easier to "push through."

Fluency training, practicing making moves accurately and quickly, holds great potential as a sport climbing procedure. Again, although elite climbers currently understand and apply versions of fluency training, the approach could be made more precise and systematic. Perhaps a stopwatch could be used to time the completion of correct moves and sequences. Faster times could then be gradually shaped.

Finally, competence in performance management might prove beneficial to climbers. In developing training programs, advanced climbers profit from periodizing their training over several months to isolate the development of aerobic endurance, strength/power and anaerobic endurance, with dedicated periods of rest. Performance goals with appropriate dimensional measurement could be established for distinctive objectives. For example, long durations of continuous movement in easy to moderate climbing characterizes aerobic endurance, whereas the number (frequency) of fingertip pull ups with a 20 lb. weight belt may prove the appropriate measure in a strength phase. Top-level climbers, for whom progress will be slower and perhaps more subtle to detect, could benefit from periodizing training and collecting data to provide more sensitive quantitative feedback on their performance. Figure 4, from *Training for Climbing* (Hörst, 2003), provides an example of just such an approach.

OPPORTUNITIES FOR RESEARCH IN SPORTS CLIMBING

Opportunities for behavior analysis research in sport climbing are great. Climbing performance can be observed directly and objectively along a host of different dimensions. In addition, the proliferation of climbing gyms and smaller-scaled, portable artificial walls provide a close simulation of actual climbing and a ready operant laboratory for controlled research. Finally, the complex, sequential, and varied nature of the motor behaviors involved in sport climbing provides opportunities for research on shaping (acquisition), chaining, and stimulus and response generalization, as suggested above. Such research should have generality to other sports in which complex motor performance is required. A logical area of applied behavioral research would be on the development of more systematic training and performance enhancement procedures. Research on shaping, chaining and fluency training in sport climbing has not been done at all, and it has been done only minimally in other more mainstream sports. Concerning applications of feedback, the use of videotaped feedback in training could be extended from research conducted with competitive swimmers (Hazen et al., 1990). For example, conducting component analyses of video-mediated feedback packages might help isolate the most critical independent variables included in the package, or help determine how certain variables influence specific types or dimensions of behavior.

Although applied research on training and performance enhancement procedures would prove practically useful, a natural science approach would suggest interest in more fundamental research on the nature of the motor behavior involved in climbing. What are the major response classes involved in sport climbing? Which are most critical steps in becoming an expert climber? What types of variables influence climbing performance?

Consider the wide range of variables that might be investigated to answer the last question. Central to an operant analysis would be analyses of climbers' reinforcers and punishers. The behavior of some climbers appears to be largely under the control of competitive social reinforcers and punishers (Did I climb better or worse than my partner?), while the behavior of others seems to be maintained by the accomplishment of personal goals. Stimulus control relationships will also be important in a comprehensive operant analysis. For example, climbers who learn to climb on artificial walls with distinctive, bolted- on holds *seem* to have trouble generalizing their behavior to natural rock. While no one has investigated that premise scientifically, there are good reasons to believe it might be true. On natural rock the holds tend to be flush with the surface, greater in number (so the climber might have to select from among several options), and of the same color. A stimulus control analysis might investigate climber performance under different conditions of hold complexity or subtlety, and as a function of prior indoor versus outdoor experience. It might suggest ways to change artificial walls to improve generality.

Finally, a broad range of historical variables such as the amount and nature of prior deliberate practice would be expected to affect performance, as suggested generally by Ericsson and colleagues (1993) and then extended to sports specifically by Starkes and Ericsson (2003). Physical variables such as sleep status, recovery time from a prior workout, overall and proximal nutritional status, and muscle flexibility of muscles are just some factors that could be affect performance in orderly ways. Sport and exercise physiologists and motor behavior researchers have conducted extensive research in this area (Wilmore & Costill, 1994), but operant analyses are needed.

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