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Changes in the perception of action possibilities while climbing to fatigue on a climbing wall

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Abstract

In two experiments we examined changes in the perception of action possibilities as a function of exertion. In Experiment 1, participants repeatedly climbed on a climbing wall in a series of trials that progressively increased in number to 10 trials, resulting in increased exertion. Before and during climbing, the participants judged their maximum reaching height and perceived exertion. On a separate day, participants climbed another 10 trials while performing actual maximum reaches. Higher perceived exertion was associated with decreases in perceived maximum reach while the actual reaches did not decrease. However, the perceptual changes occurred early during task execution when the participants were not yet fatigued. When exertion set in, neither perceived nor actual maximum reaching appeared to be affected. In Experiment 2, we included exhaustion trials. The findings replicated the early changes in perception observed in Experiment 1, which may be explained by hands-on experience with the task. Furthermore, while climbing to exhaustion, perceptual judgements largely changed in keeping with changes in the actual maximum reach. Thus, there appeared to be a functional relationship between participants' actual action capabilities, rather than their state of physical fatigue *per se*, and perceived action possibilities.

Keywords: *Perceptual judgements, affordances, effectivities, RPE scale, behavioural potential, calibration of action*

Introduction

In many sport settings there is an abundance of external and internal cues to yield relevant or irrelevant information that can be used to guide one's actions. Several factors mediating the selection of information, such as task experience (e.g. Abernethy, 2001) and competitive anxiety (e.g. Moran, Byrne, & McGlade, 2002; Williams, Davids, & Williams, 1999), have been studied extensively over the last few decades. However, the role of exertion in addressing the mechanisms by which (sport) performers pick up relevant information (Proffitt, Creem, & Zosh, 2001) has rarely been addressed. This is surprising, since many competitive sports have a clear physical component often producing physical fatigue. Sports events are often decided in the dying minutes of the game when players are tired.

In this study, we examined the influence of exertion on a perceptual judgement task – namely, perceiving overhead reachability. We chose this task for two reasons. First, in several sports, the proficiency of adequately perceiving overhead reachability is essential

to performance, for example when a ball has to be caught (e.g. baseball or basketball), hit (e.g. serving or blocking in volleyball) or punched above the head (e.g. by a soccer keeper), or when holds have to be grasped in sport climbing. Second, the actual maximum reaching height can be easily measured so that participants' perception of their action possibilities can be related to their true capabilities.

Although scarce, some empirical evidence exists for the view that perceptual judgements of action possibilities are influenced by fatigue. Proffitt and colleagues (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995) conducted a series of experiments in which they showed that perceived steepness of hills is, in part, dependent on participants' state of physical fatigue. When participants were exhausted, they judged hills to be steeper than when they were not fatigued. The authors also demonstrated that the judgement of the inclination of the hills was inversely related to the participants' fitness, and that elderly people were more prone to overestimate the steepness of hills than their younger counterparts. Moreover, participants who wore a heavy

backpack verbally judged hills to be steeper than participants without a backpack. Thus, it seems that the capacity to traverse a hill changes the perception of the steepness of that hill even though its true steepness remains the same. In other words, as hills are harder to traverse when participants are exhausted, wear a heavy backpack or are older, they are perceived to be steeper. In addition, since for biomechanical reasons hills are more difficult to descend than to ascend, hills look steeper when viewed from the top than from the bottom (Proffitt *et al.*, 1995). Thus, there seems to be a functional adaptation of perception of action possibilities to the actual action capabilities.

Bhalla and Proffitt (1999) and Proffitt *et al.* (1995, Experiment 5) studied the perception of action capabilities in a binary fashion – participants were exhausted or not, wore a heavy backpack or not, were physically fit or not, or were around 20 or above 60 years of age. Hence, they did not take into account possible intermediate changes in perception and action. Insight into these intermediate changes might provide an answer to the question of whether the adaptation of perception of action possibilities is a function of physical state *per se* or of changes in actual action capabilities, also referred to as “behavioural potential” by Proffitt and colleagues (Bhalla & Proffitt, 1999; Proffitt *et al.*, 1995). A brief discussion of Gibson’s (1979) theory of direct perception, also considered by Proffitt *et al.* (1995) as a suitable candidate to account for their findings on geographical slant perception, might underscore the relevance of this question. This theory also provides handles to distinguish the concept of physical state and that of behavioural potential or actual action capabilities.

In Gibson’s (1979) theory of direct perception (see also Michaels & Beek, 1995), affordances are defined as the behavioural possibilities of an environmental layout taken with reference to a particular animal: “An affordance for a particular animal is a property of the environment that affords relevant behavior to the animal” (Jacobs, 2001, pp. 194–195). A ball affords, for example, throwing, hitting, catching, avoiding or being hit in the head. The complement of an affordance as a property of the environment taken with reference to an animal is the property (or properties) of the animal with which that affordance can be realized. For instance, a certain arm length co-determines whether a cup on a table is reachable, and the size of the hand largely determines whether an object is graspable. Such properties, sometimes called “effectivities” within the ecological approach (e.g. Shaw, Turvey, & Mace, 1982; Turvey, 1992), thus refer to the observer’s action capabilities or behavioural potential (Bhalla & Proffitt, 1999; Proffitt *et al.*, 1995).

According to Gibson (1979), a particular affordance exists irrespective of the state or need of

that person. In other words, a change in the need or state of the observer does not alter the affordance (Gibson, 1979, pp. 138–139). Bootsma, Bakker, van Snippenberg and Tdlohreg (1992) presented support for this hypothesis in an experiment in which participants were asked to judge whether balls that passed laterally at a distance varying around arm length were reachable under two conditions: a control condition and an anxiety condition. Bootsma and colleagues found that anxiety did not influence the mean judgement of maximum reachable distance.

Bootsma *et al.* (1992) did not examine whether anxiety had an effect on the actual maximum reaching distance. The affordance of interest in their experiment was selected because it scaled with a physical characteristic (i.e. maximum reach, mainly determined by arm length), and was thus assumed not to be affected by the anxiety manipulation. However, as was also acknowledged by Bootsma and colleagues, if an experimental manipulation directly affects the action capabilities of an observer (i.e. seriously fatiguing the arm muscles before making the judgements), then a change in the perception of reachableness of approaching balls might be expected.

Thus, it would appear that as long as participants’ behavioural potential (i.e. actual action capabilities or effectivities) is not influenced by a state variable such as anxiety (or fatigue), one would anticipate that the perception of action possibilities is not influenced either. However, when a state variable does induce changes in participants’ behavioural potential, one would anticipate accompanying changes in the perception of the action possibility in question. [An in-depth discussion of the complementary concepts of “affordances” and “effectivities” can be found in a collection of papers that appeared in *Ecological Psychology* (Chemero, 2003; Heft, 2003; Jones, 2003; Michaels, 2003; Stoffregen, 2003). Although the importance of the affordance concept is widely recognized, much debate remains with regard to its precise definition and the role of effectivities in the theory of affordances (cf. Stoffregen, 2003; Turvey, 1992). To circumvent this discussion, we have chosen to use the terms “action capabilities” and “action possibilities” in the remainder of this paper. We will use the term “actual action capabilities” (cf. Michaels, 2003) to contrast it with “perceived action possibilities”.]

The present study began from the idea that there is a functional relationship between the perception of action possibilities and actual action capabilities, rather than just the observer’s state of physical fatigue, defined as a state that results from changes in skeletal muscles, the depletion of energy stores, and accumulation of lactic acid, which reduce people’s performance capacity until they drop, or

they can no longer produce the required effort (e.g. Holding, 1983; Ulmer, 1989). Using a climbing task during which judgements of overhead reachability were made, we examined whether and how perceptual judgements change as a function of exertion and action capabilities, thereby extending the work of Proffitt and colleagues (Bhalla & Proffitt, 1999; Proffitt *et al.*, 1995), who studied just the two extremes of exertion – namely, rested and exhausted.

In Experiment 1, exertion was systematically varied from rested to very fatigued. In Experiment 2 we also included exhaustion trials.

Experiment 1

In Experiment 1, participants executed a climbing task with progressively increasing exertion. This was achieved by varying the number of times participants had to climb a route from right to left and back on an artificial climbing wall. At specific moments during climbing, the participants rated their perceived exertion using Borg's (1970) ratings of perceived exertion (RPE) scale. Borg's scale is widely used to measure perceived exertion, exercise intensity or fatigue (Chen, Fan, & Moe, 2002). At those same instants, participants also judged how far they could reach overhead. At the end of the climbing tasks, blood lactate concentration was measured to obtain a confirmation of the amount of exertion. To be able to relate participants' perception of action possibilities to their actual action capabilities, we also determined participants' actual maximum reaching height at different degrees of exertion. This was done on a separate day (see "Methods"). [Noble and Robertson (1996) noted that the term "exertion" has often been criticized as inappropriate or too specific to endurance-type activities, and that some authors have suggested using other terms such as "perceived fatigue", "perceived effort" or "perceived force". Noble and Robertson concluded, "Despite such suggestions, perceived exertion has become the term generally accepted for use with all types of human movement" (p. 4). Therefore, we also use the term "perceived exertion" throughout the paper.]

We anticipated that the ratings of perceived exertion, as well as blood lactate concentration, would increase as the number of trials participants had climbed increased. Furthermore, as maximum overhead reaching involves stretching the whole body, including the reaching arm, back, shoulders and legs, and standing on tiptoe, we anticipated that at higher exertion actual maximum reaching height would decrease. Finally, we anticipated that judgements of maximum reaching height would only decrease when the actual action capabilities were also affected, irrespective of the progressive increases in exertion.

Methods

Participants. A total of 16 females (aged 19–31 years), mainly college students, volunteered to participate in the experiment. They had little or no experience in sport or rock climbing, and were naive to the purpose of the experiment. All participants signed a written informed consent, and were paid a small fee for their participation. The study's protocol was formally approved by the Local Ethics Committee of the Faculty of Human Movement Sciences before testing began.

Design. The experiment was spread over 4 days. On Day 1, the participants were accustomed to the experiment by practising the climbing task, which consisted of climbing a horizontal route on a climbing wall (see Figure 1) from the right side of the wall to the left and back to the right again, defining a single trial. On Day 2, the participants performed two series of trials. First, they climbed one of a series of 4, 6, 8 or 10 trials. After a rest of at least 1 h, the participants climbed another series of 4, 6, 8

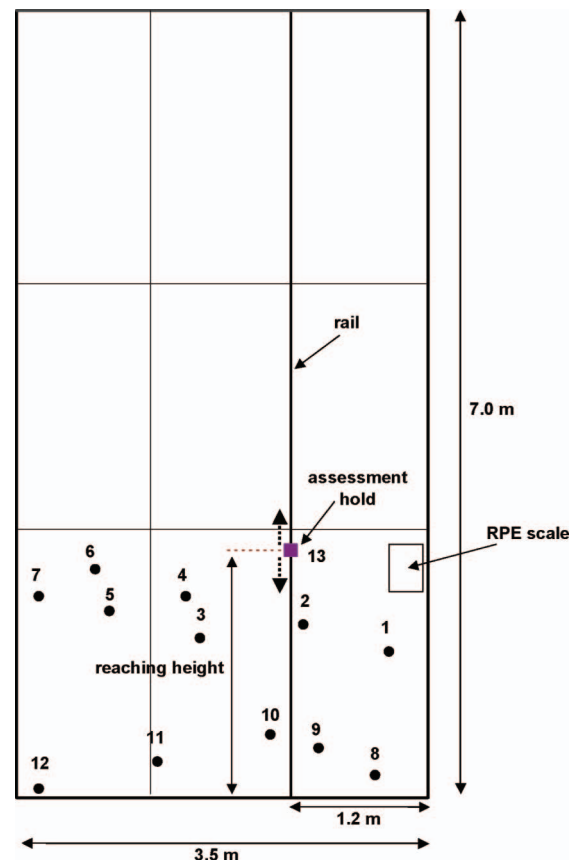


Figure 1. Front view of the layout of the climbing wall used in Experiments 1 and 2. The positions of the holds are indicated by "•" symbols. The assessment hold (Hold 13, indicated by the "■" symbol) could be moved freely along the rail. Dotted lines and the rail indicate the nine laminar panels.

or 10 trials, excluding the one they had already climbed. On Day 3, the participants climbed the remaining two series of trials. Hence, the participants performed all four series of trials to induce a “continuum” of exertion. Participants were never informed about which series of trials they were climbing to prevent them adjusting their climbing speed to that particular series, which would render the exertion manipulation ineffective. With each new participant a new order of series was selected at random (without replacement) from the 24 possible orders of the series. Before climbing and after every second trial, we assessed the participants’ *perceived* maximum reaching height and ratings of perceived exertion. On Day 4, the participants climbed 10 trials. On this day, we determined the participants’ *actual* maximum reaching height and their ratings of perceived exertion both before climbing and after every second trial, thus providing a measure of the participants’ actual action capabilities as a function of exertion.

Experimental set-up. Participants climbed on a 3° inclined (leading to backward hanging of the participants) artificial climbing wall (width 3.5 m, height 7.0 m; see Figure 1), which was placed in a gymnasium-sized laboratory. The wall consisted of nine laminate panels with a grey grainy texture for friction. Holds could be bolted anywhere on the wall at relative distances of 0.24 m horizontally and 0.17 m vertically. On the wall, a horizontal route (or “traverse”), designed by a professional route designer, was created. The route consisted of 12 holds (five footholds and seven handholds) of varying size and shape, all suitable for novice climbers. The mean height of the five footholds was 0.3 m.

One hold, the “assessment hold” (Hold 13; see Figure 1), was movable vertically. This hold was used to estimate the upper limit that participants perceived they were able to reach (the dependent variable, *perceived maximum reaching height*). The assessment hold could be moved freely along a rail, which was placed between the laminate panels of the wall and extended the entire height of the climbing wall (see Figure 1). The assessment hold was connected with ropes that could be used to pull it up or down. Reference points in the vicinity of the assessment hold (i.e. attachment locations for the holds, irregularities on the wall, edges of the panels) were removed by covering a part of the climbing wall (0.4 m on both sides of the rail) with tape. *Post hoc* interviews indicated that none of the participants had used reference points in making their assessments. Movements of the assessment hold were recorded on video during climbing (Panasonic, type NV-M5E). Hence, no time was lost to measure the height of the assessment hold so that participants could

immediately proceed with climbing after making an assessment.

Photospectrometry was used to measure blood lactate concentration (Lange, 1991). A blood sample was taken from the thumb, which was first cleaned with alcohol and then a small puncture in the skin was made with a special sterile needle. Approximately 10 μ l of arterialized capillary blood was collected in a capillary tube and immediately analysed for blood lactate concentration using a Mini analyser (Lange, 1991).

Participants’ perceived exertion was assessed during climbing using a Dutch version (Vanden Auweele, 1991) of the 15-point RPE scale (Borg, 1970, 1982, 1985), rating the task from 6 (“no exertion at all”) to 20 (“maximal exertion”). The RPE scale measures participants’ subjective evaluation of the exercise intensity with adequate reliability and validity (Chen *et al.*, 2002; Russell & Weeks, 1994; Schomer, 1987), and refers to “a general or overall perception of effort and exertion” (Borg, 1985, p. 6). Verbal anchors are used as follows (Borg, 1985): 6 = “no exertion at all”, between 7 and 8 = “extremely light”, 9 = “very light”, 11 = “light”, 13 = “somewhat hard”, 15 = “hard (heavy)”, 17 = “very hard”, 19 = “extremely hard”, and 20 = “maximal exertion”. An A3-sized RPE scale was placed on the climbing wall (see Figure 1), which allowed the participants to rate their exertion while standing on the holds.

All participants wore well-fitting climbing shoes (Enduro 954, La Sportiva). Since the standard security procedure in climbing (e.g. Skinner & McMullen, 1993) would be ineffective so low above the ground, participants were not secured.

Procedure. Each participant was tested individually. On Day 1, the participants were first informed in general terms about the procedure of the experiment. They also received a brief explanation of the RPE scale according to the guidelines of Borg (1985) and Noble and Robertson (1996) – that is, participants were told how perceived exertion was defined, how the perceptual range was anchored, the nature and use of the scale was explained, the differentiated ratings were explained, that there were no right or wrong answers and, finally, any questions were answered. Participants practised the traverse for a minimum of 10 trials. Although the climbing task was new to the participants when they entered the experiment, the climbing route was very easy and readily learned before testing began.

On Day 2 (2–8 days after Day 1), before warming up and testing, the participants were carefully instructed about what was meant by maximum reaching height. Maximum reaching height was defined according to the following reaching action

(for numbering of the holds, see Figure 1): participants had to place their left foot on Hold 9, right foot on Hold 8, right hand on Hold 1, and left hand on Hold 2, and then imagine that while stretching out upwards as far as possible (keeping both feet on the holds; standing on tiptoe was allowed) the left hand would grasp the assessment hold in such a way that they could hang on it. Participants were not actually allowed to execute the reaching action. The verbal anchors of the 15-point RPE scale were recalled. Just before starting with a series of trials (4, 6, 8, or 10 trials), the assessment of the perceived maximum reaching height was performed twice. The assessment hold (see Figure 1) was lowered from halfway up the wall and the participants had to indicate verbally when the hold would just be reachable in the prescribed manner. Corrections upwards or downwards were allowed, until the hold was at the perceived maximum reaching height. Following each separate judgement, participants were asked to look straight ahead to the climbing wall, during which the assessment hold was repositioned to halfway up the climbing wall. This procedure to assess the participants' perceived maximum reaching height was repeated. The participants were given no feedback on the accuracy of their assessments. After this, perceived exertion was rated. Then, the participants started climbing the traverse. During climbing, assessment of the perceived maximum reaching height and ratings of perceived exertion were repeated after every second trial. After making the final assessments of a particular series of trials, participants returned to a seat and a blood sample was obtained to allow measurement of blood lactate concentration. Blood samples were taken 3 min after climbing.

After a rest of at least 1 h (longer if the participants indicated that they had not fully recovered), the participants climbed another of the remaining three series of trials (for instance, if they had already climbed the 4-trial series, they now climbed the 6-, 8- or 10-trial series).

On Day 3 (one day after Day 2), the procedure of Day 2 was repeated. The remaining two series of trials were now performed (see also "Design").

On Day 4 (1–14 days after Day 3), the participants' actual maximum reaching height was determined before climbing, and after climbing 2, 4, 6, 8, and 10 trials. Participants stood on the footholds (left foot on Hold 9, right foot on Hold 8) and grasped Hold 1 with their right hand (see Figure 1), stretching out as high as possible with their left hand while an experimenter immediately positioned the assessment hold in such a way that hanging on it was just possible. The assessment hold was then secured in that position and checked to ensure that the participant could indeed just grasp the assessment hold. This

procedure was repeated. The positions of the assessment hold were again recorded on video so that afterwards participants' maximum reaching height could be determined (see "Experimental set-up"). As with the perceptual judgements, each time after the actual maximum reaching height was established, perceived exertion was rated.

Data reduction. To establish perceived and actual maximum reaching height, a frame-grabber and digitizing program (Welter, den Brinker, & van Balkom, 1996) were used to determine the image coordinates of the end position of the assessment hold. Image coordinates were translated into real-world coordinates using the direct linear transformation method (Miller, Shapiro, & McLaughlin, 1980; Shapiro, 1978). As indicated above, participants estimated their maximum reaching height twice on each occasion. The mean of the two values was taken to represent perceived maximum reaching height. Similarly, actual maximum reaching height was taken to be the mean of the two measurements taken.

Statistical analysis. Blood lactate concentration was analysed using a one-way analysis of variance (ANOVA) with repeated measures on "series (4, 6, 8, or 10 trials)". For each series of trials separately, differences in ratings of perceived exertion, and in perceived and actual maximum reaching height, were analysed using one-way analyses of variance with repeated measures on "number of trials" (ranging from "before climbing" to "10 trials"). Mauchly's test was used to determine whether there was a violation of the assumption of sphericity. If a violation occurred, it was corrected for using the Huynh-Feldt procedure before determining whether there were significant differences (Kinnear & Gray, 2000). Pair-wise comparisons using *t*-tests were made to locate differences between means when a significant main effect was found. In these cases, we followed the guidelines of "Simple Interactive Statistical Analysis" (SISA) (see <http://home.clara.net/sisa/bonhlp.htm>) for using the Bonferroni correction procedure (see Kinnear & Gray, 2002). In essence, SISA allows adding the mean correlation between the outcome variables as a parameter as it is anticipated that a set of Bonferroni-adjusted variables will be correlated. This meets the criticism of, for example, Jaccard and Wan (1996) that the Bonferroni correction procedure is too conservative, especially when the number of comparisons is large. *P*-values are reported on the basis of this SISA Bonferroni method. Effect sizes (*ES*), indicating by how many standard deviations the means under consideration differed, were calculated by taking the ratio of the difference between the two means and the mean within-cell standard deviation of the

means (Mullineaux, Bartlett, & Bennett, 2001). Effect sizes of 0.2, 0.5, and greater than 0.8 represent small, moderate, and large differences, respectively (Cohen, 1988).

Results

Ratings of perceived exertion. Table I shows the ratings of perceived exertion before climbing and during climbing the 4-, 6-, 8-, and 10-trial series climbed on Days 2 and 3. The ANOVA performed on the 4-trial series revealed a main effect of number of trials, $F_{1,30, 19.53} = 45.50$, $P < 0.001$, $ES = 1.93$. Pair-wise comparisons revealed that the ratings of perceived exertion had increased after every two trials (before climbing versus after two trials, and after two trials versus after four trials, all $t_{15} > 5.5$, all $P < 0.035$, all $ES > 0.88$). The analyses of the 6-, 8-, and 10-trial series also revealed main effects of number of trials ($F_{3, 45} = 115.08$, $P < 0.001$, $ES = 2.69$; $F_{1,43, 21.38} = 70.81$, $P < 0.001$, $ES = 3.64$; and $F_{1,90, 28.55} = 89.18$, $P < 0.001$, $ES = 5.20$, respectively). Pair-wise comparisons showed that ratings of perceived exertion were higher after every 2 trials for the 6-, 8-, and 10-trial series (all $t_{15} > 5.0$, all $P < 0.034$, all $ES > 0.80$).

The ratings of perceived exertion on Day 4, when the actual maximum reaching height was determined, are also shown in Table I (due to illness, the rating for Participant 9 was missing). The ANOVA performed on these scores revealed a main effect of number of trials ($F_{1,60, 22.43} = 100.03$, $P < 0.001$, $ES = 4.83$). Pair-wise comparisons indicated that the ratings of perceived exertion were higher after every 2 trials (all $t_{14} > 5.9$, all $P < 0.014$, all $ES > 0.86$).

To verify whether participants were rested from preceding exertions when they started a new series of trials, we determined participants' rating of perceived exertion before they climbed the first, second, third, and fourth series of trials, and analysed these data with a 2 (first series, second series) \times 2 (Day 2, Day 3) ANOVA with repeated measures on both

factors. No significant effects were found, confirming that the rest periods had been sufficiently long (all $F < 1.82$, all $P > 0.20$).

Blood lactate concentration. Box-plot analyses identified statistical outliers for Participants 2 and 3. The scores for Participant 2 were 2.0, 2.2, 7.5, and 3.0 $\text{mmol} \cdot \text{l}^{-1}$ and those for Participant 3 were 7.8, 3.5, 3.1, and 6.4 $\text{mmol} \cdot \text{l}^{-1}$ after climbing the 4-, 6-, 8-, and 10-trial series, respectively. Therefore, these two participants were excluded from subsequent statistical analysis of the blood lactate data. Blood lactate concentration was 2.7 ($s = 0.8$), 2.9 ($s = 0.7$), 3.2 ($s = 0.7$), and 3.3 ($s = 0.8$) $\text{mmol} \cdot \text{l}^{-1}$ after climbing the 4-, 6-, 8-, and 10-trial series, respectively. The main effect of series did not reach significance, although there was a trend ($F_{3, 39} = 2.47$, $P < 0.10$, $ES = 0.72$).

Taking the RPE and blood lactate data together, it is safe to conclude that exertion progressively increased with increasing number of trials within as well as across the series of climbing trials.

Actual maximum reaching height. Table II shows the means and standard deviations of the actual maximum reaching height (due to illness the results of Participant 9 are missing). An ANOVA with repeated measures on the actual maximum reaching heights comparing maximum reaching height before climbing and after 2, 4, 6, 8, and 10 trials did not show a main effect of Number of trials ($F_{3,18, 44.52} = 1.48$, $P > 0.10$).

Perceived maximum reaching height. Table II also shows the perceived maximum reaching heights for the series of 4, 6, 8, and 10 climbing trials. Note that the number of participants varied for the different statistical analyses due to technical failure of the camcorder and misinterpretation of the assessment task by one of the participants on Day 2. Furthermore, it is important to realize that the large standard deviations reported in Table II result from the

Table I. Ratings of perceived exertion for the 4-, 6-, 8-, and 10-trial series on Days 2 and 3 (after the perceptual judgements of maximum reaching height), and for the 10-trial series on Day 4 (after the actual reaches; far right column) (mean \pm s).

	Ratings after the perceptual judgements (Days 2 and 3)				Ratings after the actual reaches (Day 4)
	4-trial series ($n = 16$)	6-trial series ($n = 16$)	8-trial series ($n = 16$)	10-trial series ($n = 16$)	10-trial series ($n = 15$)
Before climbing	8.9 \pm 2.1	8.4 \pm 1.8	8.6 \pm 2.0	8.6 \pm 1.9	8.9 \pm 1.9
After 2 trials	10.6 \pm 1.8	10.4 \pm 1.9	10.3 \pm 1.9	10.3 \pm 1.6	10.5 \pm 1.7
After 4 trials	12.5 \pm 1.8	12.1 \pm 1.7	12.3 \pm 1.5	12.0 \pm 1.4	12.3 \pm 1.6
After 6 trials	–	13.4 \pm 1.4	13.6 \pm 1.8	13.5 \pm 1.0	13.9 \pm 1.3
After 8 trials	–	–	14.9 \pm 1.5	14.4 \pm 0.9	15.3 \pm 1.4
After 10 trials	–	–	–	15.4 \pm 1.2	16.5 \pm 1.6

Note: Participants' ratings of perceived exertion before climbing and after climbing 2, 4, 6, 8, and 10 trials (Experiment 1) are reported.

varying heights of the participants, a source of variance that is separated from the variance due to the independent variable (exertion) in the statistical tests (e.g. Kinnear & Gray, 2000).

For the 4-trial series, a main effect was observed for number of trials ($F_{1.47, 22.08} = 7.38, P < 0.05, ES = 0.31$). Pair-wise comparisons using *t*-tests revealed that after climbing 4 trials, perceived maximum reaching height was lower than before climbing ($t_{15} = 3.0, P < 0.047, ES = 0.31$) and after climbing 2 trials ($t_{15} = 2.6, P < 0.047, ES = 0.23$).

For the 6-trial series, there was also a main effect of number of trials ($F_{1.94, 29.05} = 5.91, P < 0.05, ES = 0.41$). Pair-wise comparisons showed that perceived maximum reaching height after climbing 2, 4 or 6 trials was lower than before climbing (all $t_{15} > 2.7, all P < 0.043, all ES > 0.21$). After climbing 6 trials, perceived maximum reaching height was lower than after climbing 2 trials ($t_{15} = 2.09, P < 0.043, ES = 0.21$).

The analysis of the series of 8 trials also yielded a main effect of number of trials ($F_{4, 46} = 4.01, P < 0.05, ES = 0.33$). In this series of trials, perceived maximum reaching height was lower after climbing 4, 6 or 8 trials than before climbing (all $t_{14} > 2.4, all P < 0.043, all ES > 0.29$). After climbing 4 or 6 trials, perceived maximum reaching height was lower than after climbing 2 trials (both $t_{14} > 2.0, both P < 0.043, both ES > 0.14$).

Finally, for the 10-trial series there was also a main effect of number of trials ($F_{3.56, 46.25} = 7.23, P < 0.001, ES = 0.38$). After climbing 4, 6, 8, or 10 trials, perceived maximum reaching height appeared to be lower than before climbing (all $t_{13} > 3.3, all P < 0.044, all ES > 0.28$). In addition, after climbing 4, 6, 8 or 10 trials, the participants assessed their maximal reach to be lower than after climbing 2 trials (all $t_{13} > 2.5, all P < 0.044, all ES > 0.14$).

Figure 2 provides a summary of the findings of the actual and perceived maximum reaching height across

Table II. Actual maximum reaching height for the 10-trial series on Day 4, and perceived maximum reaching height for the 4-, 6-, 8-, and 10-trial series on Days 2 and 3 (mean \pm s).

	Actual maximum reaching height (Day 4) (cm) (n = 15)	Perceived maximum reaching height (Days 2 and 3) (cm)			
		4-trial series (n = 16)	6-trial series (n = 16)	8-trial series (n = 15)	10-trial series (n = 14)
Before climbing	212.7 \pm 9.0	219.4 \pm 10.7	221.3 \pm 12.6	220.7 \pm 15.0	221.5 \pm 13.9
After 2 trials	214.0 \pm 8.7	218.6 \pm 11.5	218.6 \pm 12.5	218.6 \pm 15.3	219.6 \pm 14.1
After 4 trials	213.4 \pm 8.6	215.9 \pm 11.8	217.0 \pm 14.1	216.6 \pm 13.2	217.6 \pm 13.4
After 6 trials	213.0 \pm 9.2		215.8 \pm 14.4	215.8 \pm 16.0	216.6 \pm 14.2
After 8 trials	212.9 \pm 9.1			216.4 \pm 14.5	216.1 \pm 15.0
After 10 trials	212.7 \pm 8.5				216.2 \pm 14.6

Note: Participants' actual and perceived maximum reaching height before climbing and after climbing 2, 4, 6, 8, and 10 trials (Experiment 1) are reported.

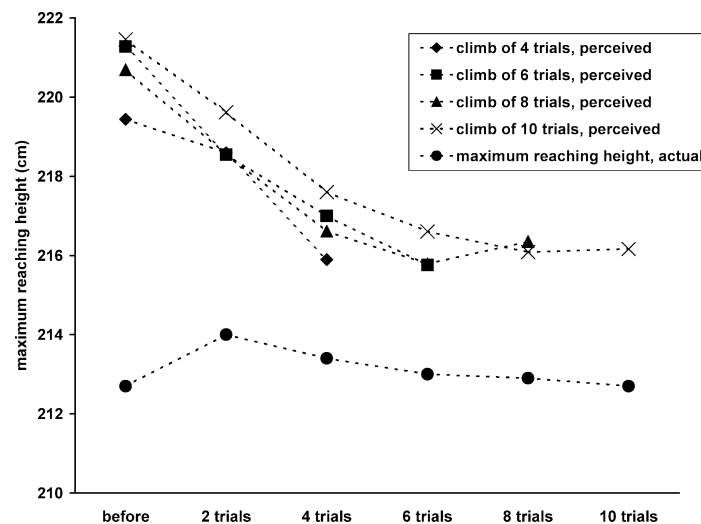


Figure 2. Perceived maximum reaching height (in cm) for the series of climbs of 4, 6, 8, and 10 trials, and actual maximum reaching height (in cm) (Experiment 1).

the series of climbing trials. As can be seen, actual maximum reaching height remained stable across the number of trials climbed. The perceptual changes were most prominent when the participants were not yet fatigued, and it appears that for higher exertion perceived maximum reaching height levels off.

Discussion

Actual maximum reaching height did not decrease as the number of trials climbed increased. Thus it seems that actual action capabilities were not affected as exertion increased. Perceived maximum reaching height decreased as perceived exertion increased. The more fatigued the participants were, the lower their perception of maximum reaching height seemed to be (see also Figure 2). Note, however, that the perceived maximum reaching height decreased in particular at the beginning of the climbing task and not at the end when higher perceived exertion was reported. After climbing two trials in which the exercise intensity was rated as “very light” to “light” (scores of 9 and 11 on the RPE scale, respectively; see Table I), the perceived maximum reaching height decreased substantially (see Table II). Moreover, the perceived maximum reaching height after climbing six or more trials – accompanied by ratings of perceived exertion of 13 (“somewhat hard”) to 15 (“hard [heavy]”) – appeared to level off (see Figure 2). This suggests that the changes in perceptual judgements that were found in this experiment were not stringently related to participants’ greater physical fatigue. At higher perceived exertion, neither perceived nor actual maximum reaching height decreased (see also Figure 2), which is in accordance with the view that judgements of maximum reaching height will only decrease when the actual action capabilities are also affected.

One possible explanation why perceived maximum reaching height decreased more after 2 and 4 trials than after 6, 8, and 10 trials might be that as the participants gained experience in climbing the traverse, they learned to pick up the relevant information to successfully execute the perceptual task. Although the experimental design, with participants climbing the 4-, 6-, 8-, and 10-trial series in different orders (and on different days), was intended to correct for order effects, short-term calibration effects (e.g. Jacobs, 2001; Jacobs & Michaels, 2002; Withagen & Michaels, 2002) might still have played a role. To investigate this, we calculated the participants’ mean perceived maximum reaching height before they climbed the first, second, third, and fourth series of trials. If the decrease in maximum reaching height after 2 and 4 trials is attributable to brief hands-on experience with the task, then lower values of perceived maximum reaching height are

anticipated when participants performed the second series of trials than when they performed the first series of trials. What should be anticipated for the third and fourth series of trials (relative to series one and two) is unclear, as they were climbed on another day than series one and two.

We tested the effects of series (first series, second series) and day (Day 2, Day 3) with a two-factor ANOVA with repeated measures on both factors. It appeared that participants judged their maximum reaching height to be lower in the second series of trials (mean 219.0, $s = 13.3$ cm) than in the first series of trials (mean 221.2, $s = 12.4$ cm) ($F_{1, 13} = 5.08$, $P < 0.05$, $ES = 0.17$). The mean perceived maximum reaching height did not differ between Day 2 and Day 3 ($F_{1, 13} = 1.32$, $P > 0.10$). The interaction between series and day was not significant ($F < 1$). Apparently, the effect of series was present on both days, suggesting that participants benefited, at least in the short run, from previous experiences with the task at hand. The brief hands-on experience with the task may have yielded perceptual information about climbing actions, which allowed calibration and led to changes in perceived maximum reaching height. In the General Discussion we return to this issue.

The design of Experiment 1 was largely dictated by our wish to manipulate exertion in a controlled manner. Therefore, all participants also climbed a maximum of 10 trials, which yielded exertion close to exhaustion in pilot testing. However, in the experiment itself the 10 climbing trials did not produce exhaustion in the majority of the participants, although many of them indicated that exertion was “hard” to “very hard” after climbing the tenth trial. Thus, it remains to be seen what the effects of exhaustion are on perceived and actual maximum reaching height in the current setting. Therefore, in Experiment 2 we asked another group of participants to climb to exhaustion, and we collected data about participants’ perceived exertion, and perceived and actual maximum reaching height, at increasing degrees of exertion.

Experiment 2

The aim of Experiment 2 was to determine whether and how perceptual judgements change as a function of exertion and action capabilities by including exhaustion trials. In Experiment 2, participants climbed twice, once to determine perceived maximum reaching height and a second time to determine actual maximum reaching height as a function of exertion. As in Experiment 1, we anticipated that the ratings of perceived exertion would increase with the number of trials climbed. Furthermore, we anticipated that exhaustion would lower the actual and consequently the perceived maximum reaching height.

Methods

Participants. Sixteen females (aged 18–29 years), mainly college students, volunteered to participate in the experiment. None of them had participated in Experiment 1, they had little or no experience in climbing, and were naive to the purpose of the experiment. All participants signed a written informed consent, and were paid a small fee for their participation. The study's protocol was formally approved by the Local Ethics Committee of the Faculty of Human Movement Sciences before the experiment began.

Experimental set-up. The participants climbed on the same climbing wall as in Experiment 1 (see Figure 1). In this experiment, the wall was not inclined but vertical, because there was no need to attempt to restrict the duration of the climbs. In Experiment 1, perceived maximum reaching height was assessed with “descending trials” only (i.e. the assessment hold was lowered), whereas usually a combination of descending and ascending trials is used for such perceptual measurements (e.g. Pufall and Dunbar, 1992). [Individuals tend to perceive their maximum reaching height to be greater on descending than on ascending trials (Pufall & Dunbar, 1992). Pufall and Dunbar considered this direction effect to be a performance characteristic of perceptual functioning: it is an indication of within-observer variability and is “systematically related to how the obstacle moves through the visual world, and correspondingly how it is tracked by the visual system” (p. 32).]

As climbing duration was no longer a serious constraint, a combination of descending and ascending trials was used in Experiment 2. The position of Hold 2 (see Figure 1) was slightly changed so as to make ascending trials possible as well. Time now also allowed perceived and actual maximum reaching height to be measured using a tape measure. Again, the Dutch version of Borg's RPE scale (Vanden Auweele, 1991) provided an index of each participant's perceived effort before climbing and after climbing every second trial. As the ratings of perceived exertion seemed to be sufficient to establish gradual changes in participants' perceived exertion, blood lactate concentration was not measured in Experiment 2. The participants wore well-fitting climbing shoes and were not secured. All climbs were videotaped using an S-VHS camcorder (sampling rate of 50 Hz) allowing inspection of specific aspects of the experiment when needed.

Procedure. For each participant (tested individually), the experiment was spread over two days. On Day 1, the participants were habituated to the experiment. They received a brief explanation of the RPE scale,

and were then instructed about what was meant by maximum reaching, upon which they had to base their judgements of maximum reaching height (see Experiment 1). Then they performed an “off-the-wall” warm-up, as we did not want to provide them with a brief hands-on experience with the climbing task. After the warm-up, the participants climbed until exhaustion. As in Experiment 1, we measured the participants' perceived maximum reaching height and ratings of perceived exertion before climbing and after climbing every second trial. Each time, perceived maximum reaching height was assessed twice. The assessment hold (see Figure 1) was lowered from halfway up the wall and the participants had verbally to indicate when the hold would just be reachable in the prescribed manner (descending trial) (see Experiment 1). Perceived maximum reaching height was determined to the nearest millimetre. Subsequently, the assessment hold was pulled up from the bottom of the wall (ascending trial) and perceived maximum reaching height was determined again. The descending and ascending trials were presented in alternating order. The participants were given no feedback on the accuracy of their assessments. After each couple of assessments, perceived exertion was rated. The participants continued climbing until exhaustion. When they rated the exercise as “extremely hard”, a score of 19 on the RPE scale, they were urged to climb another two trials whereupon the perceived maximum reaching height was determined for the last time. After that, participants stopped climbing.

On Day 2 (5–21 days after Day 1), the participants' actual maximum reaching height was determined (see Experiment 1) before climbing and after climbing every second trial until exhaustion. On each occasion that the actual maximum reaching height was established, perceived exertion was rated. As with the perceptual judgements, when participants rated the exercise as “extremely hard”, they were encouraged to climb another two trials whereupon the actual maximum reaching height was determined for the last time. After that, participants stopped climbing.

Data reduction. Each time, the mean of the descending and ascending trials was taken as perceived maximum reaching height for that moment. Similarly, actual maximum reaching height was the mean of the two measurements that were taken each time.

Statistical analysis. The ratings of perceived exertion were analysed with a 2 (Day 1, Day 2) \times 6 (number of trials: before climbing, after 2, 4, 6, and 8 trials, and after exhaustion) ANOVA with repeated measures on both factors. Perceived and actual maximum

reaching height were analysed using one-way analyses of variance with repeated measures on number of trials (before climbing, after climbing 2, 4, 6, and 8 trials, and after exhaustion). (See the Results for an explanation of the number of trials analysed.) Violations of the assumption of sphericity were treated in the same manner as in Experiment 1. Once again, the Bonferroni correction procedure was used and effect sizes were calculated (see Experiment 1).

Results

To investigate the differential effects of progressively increasing exertion, we considered it necessary to have at least six data points to achieve a continuum of exertion. Therefore, participants had to climb at least 10 trials so that we had measurements before climbing, after climbing 2, 4, 6, and 8 trials, and after exhaustion. Three participants who were unable to climb the required 10 trials were excluded from further analyses. All three had ceased their efforts because of muscle cramp. On Day 1, the number of trials after which exhaustion was reported ranged from 10 to 82 trials, with a mean of 21.8 trials ($s = 20.4$); on Day 2, it ranged from 10 to 50 trials, with a mean of 22.0 trials ($s = 13.1$). [The large difference in the maximum number of trials climbed on Days 1 and 2 can be ascribed to one participant who climbed 82 trials on Day 1 and 38 trials on Day 2. As there was no reason to exclude her from the analyses other than the extremely large number of trials climbed on Day 1, this participant was included in the analyses reported. Excluding her yielded a similar pattern of results.] An overview of the results is presented in Table III.

Ratings of perceived exertion on Days 1 and 2. The ANOVA performed on the ratings of perceived exertion (see Table III) revealed a main effect of day ($F_{1, 12} = 12.37$, $P < 0.05$, $ES = 0.98$). The

participants reported higher ratings of perceived exertion on Day 1 (mean 15.2, $s = 1.1$) than on Day 2 (mean 13.8, $s = 1.7$). There was also a main effect for number of trials ($F_{2,49, 29,87} = 138.81$, $P < 0.001$, $ES = 6.65$), indicating that the ratings of perceived exertion were higher after every two trials (all $t_{12} > 6.2$, all $P < 0.011$, all $ES > 0.66$). [Recall that the reported P -values are based on the SISA Bonferroni method (see “Statistical analysis” section of Experiment 1).] There was also a day \times number of trials interaction ($F_{3,45, 41,34} = 3.96$, $P < 0.05$, $ES = 6.33$), which mainly occurred because the difference in ratings of perceived exertion between Days 1 and 2 did not exist at the end of climbing when exhaustion was reported, and thus all ratings (both on Day 1 and Day 2) are 20 (see Table III).

Actual maximum reaching height. Analysis of the actual maximum reaching height (see also Figure 3) revealed a main effect of number of trials ($F_{3,40, 40,75} = 3.77$, $P < 0.05$, $ES = 0.60$). Pair-wise comparisons showed that after climbing to exhaustion, the participants’ actual maximum reaching height was lower than after climbing 2 or 4 trials (both $t_{12} > 3.6$, both $P < 0.034$, both $ES > 0.53$). In addition, the participants were able to reach lower after climbing 6 or 8 trials than after climbing 2 or 4 trials (all $t_{12} > 2.2$, all $P < 0.034$, all $ES > 0.27$). In summary, very high exertion affected the participants’ actual maximum reaching.

Perceived maximum reaching height. Figure 3 illustrates the participants’ perceived maximum reaching height (see also Table III). Analysis of the perceived maximum reaching height yielded a significant main effect of number of trials ($F_{3,06, 36,71} = 7.54$, $P < 0.001$, $ES = 0.95$). [Given the change from using descending trials only in Experiment 1 to a combination of descending and ascending trials in Experiment 2, it is important to note that the pattern

Table III. Ratings of perceived exertion and actual maximum reaching height on Day 2, and ratings of perceived exertion and perceived maximum reaching height on Day 1 (mean \pm s).

	Day 2		Day 1	
	Ratings of perceived exertion	Actual maximum reaching height (cm)	Ratings of perceived exertion	Perceived maximum reaching height (cm)
Before climbing	9.5 \pm 2.4	212.6 \pm 5.9	11.1 \pm 1.4	221.3 \pm 9.7
After 2 trials	11.3 \pm 2.3	214.0 \pm 5.0	12.8 \pm 1.1	217.1 \pm 11.9
After 4 trials	12.8 \pm 2.3	213.8 \pm 4.9	14.5 \pm 1.5	218.2 \pm 11.2
After 6 trials	14.2 \pm 2.3	212.4 \pm 5.5	15.8 \pm 1.8	216.7 \pm 10.4
After 8 trials	15.4 \pm 2.3	212.1 \pm 4.3	17.2 \pm 2.0	214.4 \pm 10.0
After exhaustion	20 ^a	210.7 \pm 6.8	20 ^a	210.9 \pm 12.5

Note: Participants’ ratings of perceived exertion, actual and perceived maximum reaching height before climbing and after climbing 2, 4, 6, 8, and after exhaustion (Experiment 2) are reported.

^aParticipants stopped climbing when they rated their exertion as “maximal” (RPE of 20), so no standard deviation is computed.

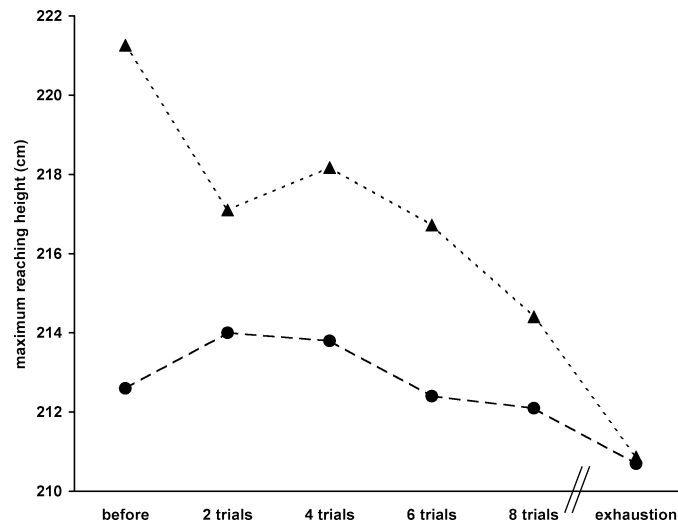


Figure 3. Perceived maximum reaching height (indicated by “▲” symbols) and actual maximum reaching height (indicated by “●” symbols), before climbing, after climbing 2, 4, 6, and 8 trials, and after climbing to exhaustion (in cm) (Experiment 2).

of results is similar when descending or ascending trials are analysed separately.] Pair-wise comparisons showed that the perceived maximum reaching height after climbing 2, 6 or 8 trials, and then after climbing to exhaustion, was lower than before climbing (all $t_{12} > 2.3$, all $P < 0.032$, all $ES > 0.38$). In addition, the participants perceived their maximum reach to be lower after climbing to exhaustion than after climbing 2, 4, and 6 trials (all $t_{12} > 2.5$, all $P < 0.032$, all $ES > 0.50$). The perceived maximum reaching height after climbing 8 trials was lower than after climbing 4 and 6 trials (both $t_{12} > 2.1$, both $P < 0.032$, both $ES > 0.22$). No differences were observed in perceived maximum reaching height after having climbed 4 trials compared to having climbed 2 trials, and after having climbed 6 trials compared to having climbed 4 trials (both $t_{12} < 1.7$, both $P > 0.032$). There was no difference between 8 trials and exhaustion ($t_{12} = 1.6$, $P > 0.032$).

Discussion

As in Experiment 1, each time participants climbed another two trials they reported more exertion than before climbing the two trials, which indicates that the manipulation of exertion was successful. For exertion perceived to be “light” (RPE of about 11) to “hard” (RPE of about 15), the participants’ actual maximum reaching height was not affected. With higher exertion and after exhaustion, the participants’ actual maximum reaching height was affected, leading to lower reaches. The changes in actual maximal reaching height may seem small (range 211–214 cm), but note that the actual range of reachability is probably closer to, say, 40 cm (i.e. maximum reaching height minus physical height) or even less. Even when exhausted, one will succeed in raising one’s hand

above one’s head. In that light, the observed decrease in actual maximum reaching height is both substantial and meaningful, as it might, for instance, be decisive in whether a route can be climbed or not.

As in Experiment 1, the perceived maximum reaching height decreased in particular at the beginning of the climbing task (see Figure 3) when fatigue had not yet set in. In addition, for exertion perceived to be “light” (RPE of about 11) to “hard” (RPE of about 15), the perceived maximum reaching height did not change. At the moment that exercise intensities were rated as “very hard” and higher (RPE of 17 and more), the perceived maximum reaching height again declined significantly (see Table III). Overall, these findings indicate that changes in perceived maximum reaching height followed changes in actual maximum reaching height rather than changes in exertion.

General discussion

In the present study, we examined the relationship between perception of action possibilities, actual action capabilities, and progressing amounts of exertion in the context of wall climbing. Three aspects to this relationship became apparent in the results of Experiments 1 and 2 (see Figures 2 and 3). First, when participants were not yet fatigued, a rapid decrease in perceived maximum reaching height was observed, while the actual maximum reaching height remained constant. Second, exertion rated as “light” (RPE of about 11) to “hard” (RPE of about 15) neither affected the actual nor the perceived maximum reaching height. Third, when exertion was rated as “very/extremely hard” (RPE of 18/19) to “maximal” (RPE of 20), participants’ actual maximum reaching height declined, which was accompanied by a

decrease in their perceived maximum reaching height. Let us now discuss each of these aspects in detail.

First, brief hands-on experience with the task (see Discussion of Experiment 1) seems to be responsible for the early changes in perceived maximum reaching height that were found in both experiments. Scaling of perceptual judgements on the basis of exploratory behaviour was also reported by Mark (1987), who found that after a change in eye-height of 10 cm, observers quickly recalibrated their judgements of maximal sitting and stepping height when they were allowed to move and employ information-gathering activities such as locomotion and head turning. In climbing the first few trials, the participants in the present experiments could have calibrated their actions in relation to their environment leading to more accurate (lower) judgements of maximum reaching height after climbing two trials. This adaptation appeared to be functional because participants started with apparent overestimations. Furthermore, the adaptation in question occurred each time anew, as is apparent from the fact that calibration effects were visible on the different testing days (see Discussion of Experiment 1).

Second, light to hard perceived exertion affected neither actual nor perceived maximum reaching height. Thus, although the physical state of the participants changed in that they became more fatigued, it did not affect their judgements of maximum reaching height, which again seemed to be functional, as the participants' action capabilities remained unaffected.

Third, as soon as changes in the participants' action capabilities occurred, as was the case when perceived exertion was rated as "very hard" to "maximal", changes in perception of action possibilities were also apparent. Thus, perceived maximum reaching height seemed to follow changes in actual maximum reaching height, rather than the state of physical fatigue of the observer.

These results indicate that changes in perceived exertion are not necessarily related to changes in perception of action possibilities. Changes in the perception of action possibilities only occur when changes in participants' actual action capabilities have occurred. Thus, the perception of the environment in terms of action possibilities does not change when the observer is, for instance, somewhat fatigued, anxious or hungry. Our findings are consistent with Gibson's (1979) original ideas about affordances that a change in need or state of the observer does not immediately alter affordances, and hence the perception of affordances. Only when the observer's action capabilities are affected (e.g. when exhausted) is the perception of the action possibilities also affected.

This does not imply that changes in an observer's state or need without changes in action capabilities

have no effect at all on the perception and realization of affordances. A person's internal state plays an important role in the selection of affordances, as people have to select which affordances they wish to realize among the many that are afforded by the environment, depending on their intentions (Gibson, 1979; Michaels, 2003; Stoffregen, 2003). It is likely that people's intentions, and hence the selection of affordances, are constrained by the person's state or need. As Gibson (1979) put it, "The observer may or may not perceive or attend to the affordance, according to its needs, but the affordance, being invariant, is always there to be perceived" (p. 139). Thus, the state or need of an observer is of relevance in constraining the choice of action modes to achieve a particular goal (Mark *et al.*, 1997; Stoffregen, 2003).

It is important to note that the functional relationship between actual action capabilities and perceived action possibilities does not mean that absolute values of the estimations should be a perfect match of the actual action capabilities. Just as in other research into the perception of reaching possibilities (e.g. Bootsma *et al.*, 1992; Carello, Groszofsky, Reichel, Solomon, & Turvey, 1989; Heft, 1993; Pepping & Li, 1997; Pufall & Dunbar, 1992), reaching height was generally overestimated in our study. In this respect, Heft (1993) showed that verbal judgements of action possibilities invite an analytical attitude transforming what is typically a skilled, unreflective perception-action process into a reflective judgement. When judgements of reach were a means to complete another task, the analytical attitude was circumvented and the assessments of perceived reach were more accurate (Heft, 1993).

As an aside, this seems to be in accordance with recent findings that there are two anatomically distinct streams for visual information processing: the ventral and the dorsal stream, each serving quite different functions dubbed vision for perception and vision for action, respectively (e.g. Goodale & Haffenden, 1998; Milner & Goodale, 1995). Vision for perception is mainly concerned with representing the world – that is, the explicit knowledge of environmental properties. Vision for action is primarily concerned with the control of action in the environment (Goodale & Haffenden, 1998; Goodale & Humphrey, 1998; Milner & Goodale, 1995; Norman, 2002). By implication, verbal judgements tap the ventral rather than the dorsal stream providing "information for perception" that is not necessarily accurate (Goodale & Humphrey, 1998; van der Kamp, Savelsbergh, & Rosengren, 2001). Vision for action, as supported by dorsal stream activity, should be accurate and requires "veridical evaluation of the surface layout for effective interaction with the immediate environment" (Bhalla & Proffitt, 1999, p. 1093). The use of verbal reports in our study may

have contributed to the overestimations of maximum reaching height.

Conclusions

The results of the present study support two main conclusions. First, early during task execution when fatigue was not yet present, changes in perceived maximum reaching height occurred. The brief hands-on experience with the task could have produced or exposed relevant perceptual information about climbing actions, which allowed calibration to occur and led to changes in perceived maximum reaching height. Second, and most important for the present study, there appears to be a functional fit between participants' actual action capabilities rather than their physical state of fatigue and perceived action possibilities. Apart from the early changes, perceived maximum reaching height followed the changes in action capabilities. When there were no such changes (at moderate amounts of perceived exertion), no changes in perceived action possibilities occurred. Only when actual maximum reaching height changed (i.e. with higher perceived exertion), was this reflected by perceptual changes. Thus, perceptual judgements about action possibilities may change only at high and not low exertion.

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