Hunt, D., Hunt, H. B. N., & Park, J. H. (2017). Bioenergetic costs and state influence distance perception. *Physiology and Behavior*, *180*, 103-106. https://doi.org/10.1016/j.physbeh.2017.08.003

Bioenergetic Costs and State Influence Distance Perception

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Abstract

Bioenergetic resources and states have been found to influence visual perception, with greater expected energy expenditure being associated with perceptions of greater distances and steeper slopes. Here we tested whether resting metabolic rate (RMR), which can serve as a proxy for the bioenergetic costs of completing physical activity, is positively correlated with perceived distance. We also tested whether temporarily depleting bioenergetic resources through exercise would result in greater perceived distance. Eighty-two members of the public were recruited at a beach in Weston-super-Mare, UK. Half completed moderate exercise and half acted as controls. They then estimated distance to a set point. Results showed that RMR (computed using a recognized equation) was positively correlated with distance perception, meaning that participants requiring greater energy to traverse a set distance perceived the set point as farther away. In addition, those participants who had their bioenergetic resources temporarily depleted through exercise perceived the set distance as greater, compared to controls. There was no interaction effect between RMR and exercise. To our knowledge, these results are the first to show a relationship between metabolic rate and distance perception, and they contribute to the literature on embodied perception.

Keywords: Embodied perception, distance perception, bioenergetic costs, metabolic rate.

1. Introduction

A central tenet for the survival of any organism is to ensure that energy output does not exceed energy input for any long period of time. For human hunter–gatherers, this would have meant that the energy expended in obtaining food (e.g., traveling to an area to collect berries or hunting prey) must not have consistently exceeded the energy gained from consuming it. One implication is that perception may have evolved to be attuned to the functional consequences of engaging in action under varying conditions. Proffitt (2006) suggested that humans have developed an *economy of action* that influences visual perception in an adaptive manner by taking into account factors such as the bioenergetic cost of performing an action and the current bioenergetic state (Proffitt, 2006; Witt, 2011). Essentially, expectations of greater energy expenditure may shift perception to make a physical activity appear more effortful, such as a distance appearing greater or a slope appearing steeper, which would discourage the activity.

Studies have demonstrated that factors such as body size (Eves, Thorpe, Lewis, & Taylor-Covill, 2014; Linkenauger, Witt, & Proffitt, 2011; Sugovic, Turk, & Witt, 2016; Van der Hoort & Ehrsson, 2014), waist-to-hip ratios (Cole, Balcetis, & Zhang, 2013), physical fitness, measured by VO_2 max thresholds (Zadra, Weltman, & Proffitt, 2016), and excessive bodyweight (Taylor-Covill & Eves, 2015) can influence the potential for someone to engage in physical activity. Furthermore, current resources and temporary encumbrances can also influence perception. For example, wearing a heavy backpack can increase the perceived effort for conducting in potential physical activity and influence perceptions, making hills appear steeper and distances appear as if they are farther away (Bhalla & Proffitt, 1999; Proffitt, Stefanucci, Banton, & Epstein, 2003). Conversely, increasing bioenergetic potential by consuming additional carbohydrates, can make hills appear less steep and distances appear shorter (Schnall, Zadra, & Proffitt, 2010; Zadra et al., 2016) in an adaptive manner.

These studies discussed above take into account the physical potential of an individual (e.g., waist-to-hip ratio; Cole & Balcetis, 2013), but do not necessarily take into account the amount of energy that would be expended in conducting a physical activity. Moreover, measurements, such as waist-to-hip ratios, do not consider age. Resting metabolic rate (RMR) offers a conceptually different measure, focusing less on physiological potential and more on actual bioenergetic costs (DeLany, Kelley, Hames, Jakicic, & Goodpaster, 2013).RMR is an established method for calculating metabolic rate and the amount of energy that require in order to maintain their current size. Moreover, and as illustrated in Figure 1, RMR is an inclusive measure that takes into account a number of factors, providing a holistic view of the energetic expenditure that an individual may have. RMR can be used to infer the general amount of energy that is required to complete a physical activity, such as traversing a distance by foot. Individuals who chronically expend more energy for physical activity may have a perceptual system that is biased towards motivating them against physical activity, especially in situations where nothing will be gained. The higher the metabolic rate, the more energy would be expended with any form of physical activity (DeLany et al., 2013). Outside of extreme situations, RMR is usually the largest single component for calorie expenditure. While gas exchange can be used to measure RMR, this method requires expensive equipment and complicated procedures. Alternatively, statistical methods, such as the Mifflin-St Jeor equation (Mifflin et al., 1990) can be used to reliably estimate resting metabolic rates (Frankenfield, Roth-Yousey, Compher, & Evidence Analysis Working Group, 2005).

In addition to the effect of stable individual differences in energy expenditure, temporary depletion of bioenergetic resources could also have an effect. Similar to those individuals who were encumbered with a backpack, individuals who are temporarily fatigued may view a distance as greater, which may motivate avoidance of completing the action.

Indeed, research has already demonstrated that the slant of hills appears steeper when participants are fatigued compared to controls (Proffitt, Bhalla, Gossweiler, & Midgett, 1995).

The present study was designed to simultaneously test two predictions regarding the impact of two different factors that may be associated with distance perception. The first prediction was that those with a higher RMR would perceive a set distance as being greater. The second prediction was that those who are experimentally manipulated into a fatigued state (by engaging in light exercise) would perceive a set distance as being greater compared to controls. We had no specific prediction regarding whether RMR and the experimental manipulation would have an interaction effect (such that the exercise manipulation has a larger effect on distance perception among individuals higher or lower in RMR). In order to maximize the variation in RMR values, members of the public were recruited to take part.

2. Method

2.1. Participants and Design

Eighty-two members of the public (45 women, 37 men; mean age = 53.63 years, *SD* = 16.64) recruited with an opportunistic sampling method on Weston-super-Mare (UK) beach participated in exchange for £2. (Data from one additional participant was excluded due to not providing consent for their data to be used for the purposes of research.) Participants were randomly assigned to the exercise (*n* = 41) or the control (*n* = 41) condition. This study was the first in which these specific predictions were tested; it also involved a unique sample and a unique distance. Therefore, there was no empirical precedent that would allow us to determine an appropriate sample size based on statistical power.

2.2. Materials and Apparatus

2.2.1. Stepper. Figure S1 provides a photographic image of the stepper that was used with participants in the exercise condition. The resistance setting and duration of exercise were calibrated to induce a notably fatigued state, while being achievable for participants of varying abilities. This was achieved by conducting an informal pretest, allowing people of varying abilities to try the stepper at different resistance settings. Additionally, participants were asked to go as quick as possible for the full duration, in order to ensure that they achieved a fatigued state.

2.2.2. Distance Estimate Target. Figure S2 provides a photographic image of the distance estimate target from the participant's vantage point. This particular location was selected as there were no visual cues (e.g., streetlights) that participants could use as approximate units of measure. The target itself was a wooden poll that was approximately 200cm in height and had a yellow triangle at the top. The actual distance to the target was 92.5 meters, as measured using a measuring wheel. A one-meter rule was provided as a reference guide to all participants when they estimated the distance to the target.

2.2.3. Height and Weight. Height was measured using a tape measure that was fixed to the shelter where the study took place. Weight was taken using a digital scale. A cardboard base was used to provide a level ground and all weight measures were taken in the same location in order to achieve consistency.

2.2.4. Resting Metabolic Rate. The Mifflin-St Jeor equation (Mifflin et al., 1990) was used as it has been recognized as a reliable method for measuring metabolic rate (Frankenfield et al., 2005; Frankenfield, Rowe, Smith, & Cooney, 2003). Figure 1 shows the equation used to compute resting metabolic rates.

2.2.5. Manipulation Check. A 6-point scale (1 = not at all, 6 = extremely) was used to measure fatigue. The question asked was "On scale of one to six, one meaning not at all, and six meaning extremely, how fatigued do you currently feel?"

2.3. Procedure

Participants were first asked to provide their age, gender, and ethnicity. Height and weight measures were then taken. Next, participants in the exercise condition were asked to complete 90 seconds of exercise on the stepper and to go as quickly as they could. Immediately after the exercise phase, participants were taken to a set point that was approximately 3 meters away to make their distance estimate. Participants in the control condition were asked to make their distance estimate immediately after their height and weight measures were taken. In order to ensure that there were no issues with participants' knowledge of metric units, participants were provided with a one-meter rule to serve as a reference guide. Participants were asked to provide their estimate to the nearest meter. Finally, all participants reported how fatigued they were. A short explanation of the term 'fatigue' was provided in order to make sure that all participants understood the question being asked.

3. Results

Table 1 shows the descriptive statistics for the physiological measures (age, height, weight, BMI, and RMR). Table 2 showed the same values, separated by gender. Men had higher RMR values than did women, $t(80) = 8.83$, $p < .001$. Distance estimates ranged from 5 to 250 ($M = 89.49$, $SD = 47.99$).

To check whether the exercise manipulation made participants more fatigued, an independent samples *t*-test was conducted. Results revealed that participants in the exercise condition ($M = 2.32$, $SD = 1.27$) reported higher levels of fatigue compared to controls ($M = 1.51$, $SD = 0.95$), $t(80) = 3.24$, $p = .002$, $d = 0.72$.

We analyzed whether those who were fatigued perceived the distance as being greater compared to controls. Those in the exercise condition ($M = 102.66$, $SD = 41.37$) perceived the distance as being greater compared to those in the control condition ($M = 76.32$, $SD = 50.96$), $t(80) = 2.57$, $p = .01$, $d = 0.57$. We then investigated whether there were any gender differences in distance estimates. An independent samples *t*-test revealed that men perceived the distance as marginally farther (*M* = 100.49 meters, *SD* = 49.96) than did women (*M* = 80.44 meters, *SD* = 44.85), *t*(80) = 1.91, *p* = .059, *d* = 0.42. Next, we examined the relationship between RMR and distance estimates. Using a simultaneous multiple regression analysis, we entered RMR, condition, gender, condition x RMR interaction, and gender x RMR interaction as predictors, and distance estimates as the dependent variable (see Table 3). The model accounted for 18% of the variance in distance estimates, $F(5, 76) = 3.35$, $p < .01$, $R^2 = .18$. RMR ($\beta = .52$, $p = .04$) and condition ($\beta = -.28$, $p = .01$) were significant predictors of distance estimates, meaning those with higher RMR and those fatigued by exercise gave larger distance estimates.

Due to the large variation and extremes in distance estimates (see Figure 2 for a Frequency Distribution), a secondary analysis was conducted with a subsample of the data to investigate. Using frequency data, the top and bottom 10% of distance estimates were removed. The Kolmogorov-Smirnov analysis was conducted to test the goodness-of-fit of the new subsample. Results revealed that this new subsample did not deviate from normality, D(70) = .10, *p* = .20. The subsample had a total of 70 participants (36 in the exercise condition and 34 in the control condition). Distance estimates ranged from 30 to 150 metres (*M* = 84.29, *SD* = 32.97). First, we analyzed whether those who were fatigued, perceived the distance as being greater compared to controls. Those in the exercise condition (*M* = 96.72, *SD* = 32.35) perceived the distance as being greater compared to those in the control condition (*M* = 71.12, *SD* = 28.56), *t*(68) = 3.50, *p* = < .01, *d* = 0.86. Repeating the same regression analysis as above yielded a model that accounted for 28% of the variance in distance dstimates, $F(5, 64) = 5.01$, $p < .01$, $R^2 = .28$ (see Table 4). The main effects of RMR ($\beta = .63$, $p = .03$) and condition ($\beta = -.43$, $p < .001$) remained significant. The results from the subsample confirm that the results from the initial analyses cannot be explained by outliers unduly influencing the results.

4. Discussion

This study had two aims. The first was to test whether baseline bioenergetic costs, measured through resting metabolic rate, would be associated with distance perception. The second was to test whether depleting bioenergetic resources, through exercise, would influence distance perception. Consistent with both predictions, higher metabolic costs (operationalized by RMR) were found to be associated with perceiving the set distance as greater and participants who engaged in light exercise perceived the set distance to be greater compared to those that did not complete any exercise. There was no evidence of an interaction effect between RMR and exercise.

These findings support the notion that visual perception is influenced by economy of action and the broader logic of embodied perception (Proffitt, 2006). From an evolutionary perspective, a system designed to consider the energy expended in performing physical activity would be adaptive, especially in situations when there is no incentive. The ability to survive, especially in an environment where energy consumption can be highly variable (e.g., hunter–gatherer communities) relies heavily on conservation of energy. Perceptual systems, resources availability, and an individual’s abilities collectively guide whether motor actions should be deployed or not. While traversing short distances may not expend vast amounts of energy, the cumulative energy expenditure could mean the difference between surviving or not.

Diverging somewhat from the new look account of perception (e.g., Balcetis & Dunning, 2010; Cole, Balcetis, & Dunning, 2013) that hinges on the beliefs of the perceiver (e.g., desirability and threat), these findings focus on the physiological capabilities and energy costs involved in physical activity (e.g., affordance of action; Proffitt, 2006). They provide support for top-down influences that show a relationship between engaging in motor activities and a perceptual system that either promotes engaging or avoiding these actions.

In line with previous research, body weight was found to be positively correlated with perceived distance (e.g., Sugovic et al., 2016). However, bodyweight provides a more indirect measure of bioenergy considerations, whereas RMR provides a more direct measure. RMR equations offer a practicable alternative to indirect caliometry, but there will always be an element of noise, due to factors such as body composition, that do not form part of these equations. To our knowledge, this is the first study to show a relationship between metabolic rate and distance perception.

One limitation of this study is that the exercise was relatively undemanding, so it is difficult to ascertain whether the results can be attributed to a truly fatigued state. Indeed, looking at the self-report fatigue ratings, the mean average was 2.32 out of 6, and this is relatively low. Of course, this may simply reflect the limitation of the self-report measure of fatigue. Also, it could be the case that people need to be only slightly fatigued before changes in perception start to occur. Future studies may therefore utilize more demanding activities, to test the effects of a more truly fatigued state. Moreover, complementary physiological measure of fatigue could be used to corroborate self-report ratings (e.g., heart rate changes).

Another limitation of this study could be that fitness states were not recorded. While RMR is likely to act as a good predictor for energy expenditure in traversing a set distance, participants' level of fitness is also likely to influence their overall capabilities. Indeed, this has been found in previous studies (Balcetis, Cole, & Bisi, 2015; Cole & Balcetis, 2013; Cole et al., 2013). Future studies, investigating the role of RMR on perception may look to incorporate a measure of fitness, such as those used in the studies mentioned.

These findings may also shed light on the difficulty that some individuals experience when engaging in exercise in order to lose weight. Part of losing weight can rely on physical activities, such as walking. If heavier individuals are likely to expend larger amounts of energy, their perceptual systems are likely to make these activities appear even harder, demotivating them from engaging in these activities. Despite this discouraging view, it is also clear that perception can be manipulated, and future studies may seek to investigate this further.

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Table 1

Mean scores, SDs and ranges for each physiological measure used (N = 82).

Variable	Mean	SD	Minimum	Maximum
Age	53.63	16.64	18.00	82.00
Weight	72.89	15.15	44.20	111.70
Height	1.70	0.11	1.28	1.91
BMI	25.30	4.94	16.04	41.03
RMR	1436.02	260.46	933.50	2035.00

Note 1: Units of measurement; age (years), weight (kilograms), height (meters). Note 2: For equations used to calculate BMI, and RMR.

Table 2

Mean scores, SDS, and ranges for each physiological measure used, separated by gender.

	Variable	Mean	SD	Minimum	Maximum
Male	Age	56.54	17.03	18.00	82.00
	Weight	80.40	13.37	55.90	105.50
	Height	1.78	0.07	1.64	1.91
	BMI	25.44	3.69	19.34	32.52
	RMR	1636.60	191.79	1249.00	2035.00
Female	Age	51.24	16.11	18.00	82.00
	Weight	66.71	13.76	44.20	111.70
	Height	1.63	0.09	1.28	1.80
	BMI	25.17	5.80	16.04	41.03
	RMR	1271.09	182.05	933.50	1767.25

Note 1: Units of measurement; age (years), weight (kilograms), height (meters). Note 2: For equations used to calculate BMI, and RMR.. Note 3: Males (n = 37) and females (n = 45).

Table 3

Results from a simultaneous multiple regression analysis testing effects of Resting Metabolic Rate (RMR), Condition (0 = exercise, 1 = control), Gender (0 = male, 1 = female), and interactions with Condition and Gender on Distance Estimates

Predictor	b	SE_b	β	t	p
RMR	.10	.05	.52	2.07	.04
Condition	-26.62	10.04	-.28	-2.65	.01
Gender	-2.41	14.21	-.03	-.17	.87
Condition X RMR	-.03	.04	-.12	-.74	.46
Gender X RMR	-.06	.05	-.19	-1.07	.29

Note 1: See Figure 1 for the equation to compute RMR..

Table 4

Results from a simultaneous multiple regression analysis on the subsample, testing effects of Resting Metabolic Rate (RMR), Condition (0 = exercise, 1 = control), Gender (0 = male, 1 = female), and interactions with Condition and Gender on Distance Estimates

Predictor	*b*	SE_b	*β*	*t*	*p*
RMR	.09	.04	.63	2.26	.03
Condition	-27.89	7.07	-.43	-3.95	< .001
Gender	4.24	9.92	.07	.43	.67
Condition X RMR	-.01	.03	-.05	-.30	.77
Gender X RMR	-.07	.04	-.29	-1.59	.12

Note 1: See Figure 1 for the equation to compute RMR.

Figure 1

Mifflin St Jeor Equation used to Calculate Resting Metabolic Rate (RMR)

Males

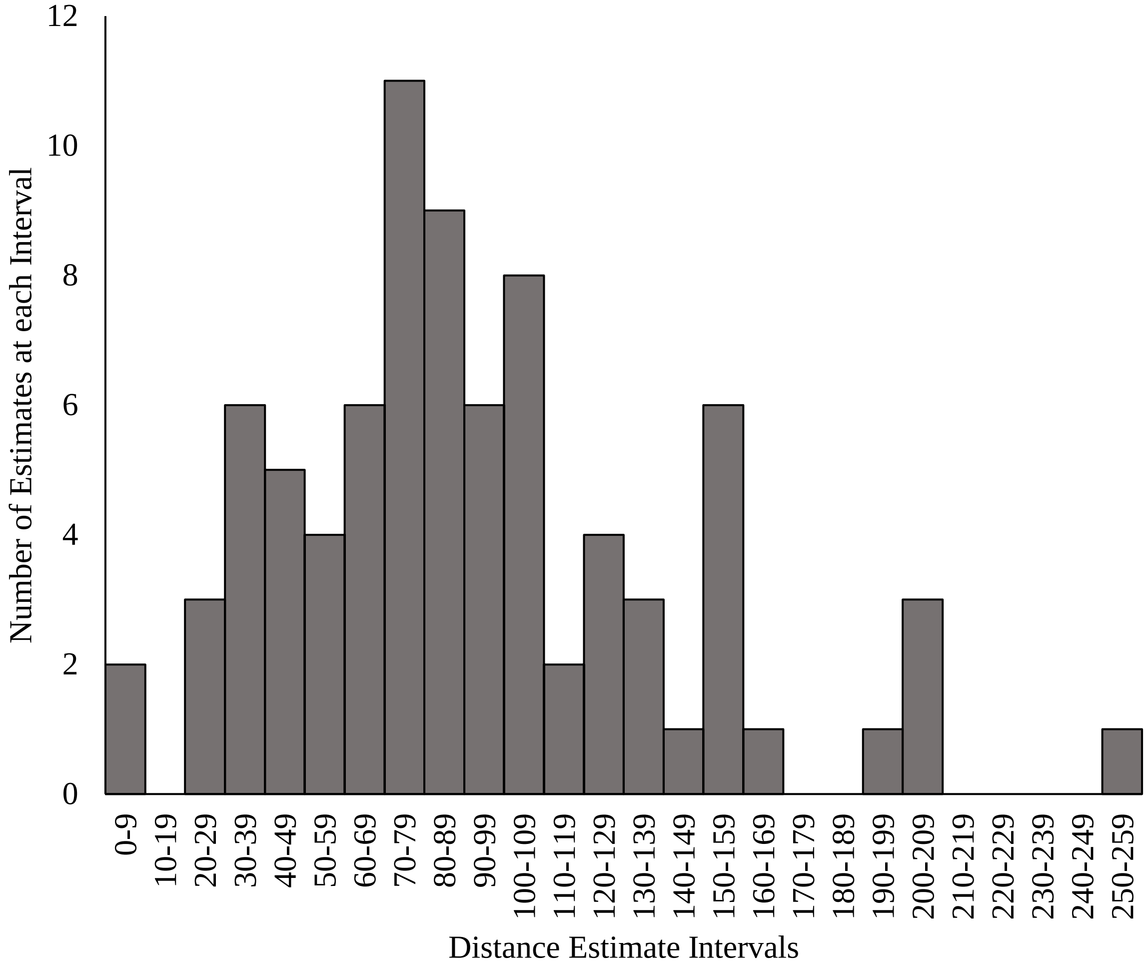
10 x weight (kg) + 6.25 x height (cm) – 5 x age (y) + 5

Females

10 x weight (kg) + 6.25 x height (cm) – 5 x age (y) – 16

Figure 2

A Histogram showing the Frequency Distribution of Distance Estimates (N = 82)


12
10
8
6
4
2
0
Number of Estimates at each Interval
0-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-119
120-129
130-139
140-149
150-159
160-169
170-179
180-189
190-199
200-209
210-219
220-229
230-239
240-249
250-259
Distance Estimate Intervals