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**The effects of facial expression and relaxation cues on movement economy,
physiological, and perceptual responses during running.**

Noel E. Brick^a, Megan J. McElhinney^b, Richard S. Metcalfe^{c,d}

^a Psychology Research Institute, Ulster University, Magee Campus, Derry, Northern Ireland

^b School of Psychology, Ulster University, Magee Campus, Derry, Northern Ireland

^c School of Sport, Ulster University, Jordanstown Campus, Shore Road, Newtownabbey, Co

Antrim, Northern Ireland. BT37 0QB

^d Applied Sports Science Technology and Medicine Research Centre (A-STEM), Swansea

University, Swansea, UK. SA1 8EN

Corresponding author details: Dr Noel E. Brick. Psychology Research Institute, Ulster
University, Magee Campus, Derry, Northern Ireland. BT48 7JL. Tele: +44 (0)28 71675366.
Email: n.brick@ulster.ac.uk

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4 **The effects of facial expression and relaxation cues on movement economy,**
5 **physiological, and perceptual responses during running.**

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7 **Abstract**

8 *Objectives:* Previous research has supported the beneficial effects of relaxation training on
 9 running economy. However, no studies have compared the effects of brief contact
 10 instructions to alter facial expression or to relax on running economy or running performance.
 11 The primary aim of this study was to determine the effect of such attentional instructions on
 12 movement economy, physiological, and perceptual responses during running. *Method:* Using
 13 a repeated measures design, 24 trained runners completed four 6 min running blocks at 70%
 14 of velocity at VO_{2max} with 2 min rest between blocks. Condition order was randomized.
 15 Participants completed running blocks while smiling, frowning, consciously relaxing their
 16 hands and upper-body, or with a normal attentional focus (control). Cardiorespiratory
 17 responses were recorded continuously and participants reported perceived effort, affective
 18 valence, and activation after each condition. *Results:* Oxygen consumption was lower during
 19 smiling than frowning ($d = -0.23$) and control ($d = -0.19$) conditions. Fourteen participants
 20 were most economical when smiling in contrast with only one participant when consciously
 21 relaxing. Perceived effort was higher during frowning than smiling ($d = 0.58$) and relaxing (d
 22 $= 0.49$). Activation was higher during frowning than all other conditions (all $d \geq 0.59$). Heart
 23 rate, affective valence, and manipulation adherence did not differ between conditions.
 24 *Conclusion:* Periodic smiling may improve movement economy during vigorous intensity
 25 running. In contrast, frowning may increase both effort perception and activation. A
 26 conscious focus on relaxing was not more efficacious on any outcome. The findings have
 27 implications for applied practice to improve endurance performance.

28 **Keywords:** Smiling; relaxation; endurance activity; running economy; attentional focus

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Introduction

31 Physiological factors related to prolonged endurance performance (e.g., marathon running)
 32 include the maximal amount of oxygen that can be utilized (VO_{2max}), lactate threshold (i.e.,
 33 the intensity at which blood lactate first rises above baseline levels) and movement economy
 34 (e.g., Jones, 2006; Joyner, 1991). Running economy (RE) can be defined as the steady-state
 35 volume of oxygen consumed (VO_2) during a submaximal running intensity (Conley &
 36 Krahenbuhl, 1980) and can explain differences in performance between athletes otherwise
 37 matched in terms VO_{2max} and lactate threshold (e.g., Joyner, 1991; Moore, 2016).
 38 Improvements in RE are associated with chronic adaptations to both endurance (e.g., Barnes
 39 & Kilding, 2015) and strength (e.g., Barnes, Hopkins, McGuigan, Northuis, & Kilding, 2013)
 40 training, as well as manipulations to improve biomechanical and technical aspects of the
 41 running movement (e.g., Moore, 2016). To emphasize the importance of RE, long-term
 42 reductions in the oxygen cost of movement have been strongly associated with performance
 43 optimization in the most elite distance runners (Jones, 2006).

44 Psychological strategies are also important for endurance performance (e.g., Brick,
 45 MacIntyre, & Campbell, 2014) and can impact RE (e.g., Neumann & Piercy, 2013; Schücker,
 46 Schmeing, & Hagemann, 2016). Early research by Morgan and Pollock (1977) suggested that
 47 elite marathon runners typically used associative cognitive strategies (i.e., pay attention to
 48 sensory information and modulate pace accordingly), whereas non-elite performers tended to
 49 distract from sensations experienced during running (i.e., dissociate). One regulatory strategy
 50 was relaxation, whereby runners, ‘paid very close attention to bodily input... [and] constantly
 51 reminded or told themselves to “relax,” “stay loose,” and so forth’ (p. 390). Relaxation during
 52 running was considered responsible in part for a lower relative oxygen consumption amongst
 53 the elite marathoners in comparison with elite middle-distance runners. Subsequent research
 54 has supported the importance of relaxation to improved RE. Williams, Krahenbuhl, and

55 Morgan (1991) noted a positive relationship between lower tension (as a mood state) and
56 improved RE, for example. In addition, Smith, Gill, Crews, Hopewell, and Morgan (1995)
57 reported the most economical participants in their study used more relaxation during running.

58 Several potential mechanisms may explain why a relaxed state would improve RE.
59 These include reduced autonomic sympathetic nervous system activity and a concomitant
60 decrease in heart rate and muscle activation (i.e., the relaxation response; Benson, Dryer, &
61 Hartley, 1978). In a running context, researchers have attempted to improve RE using brief
62 contact relaxation interventions comprising advanced psychological methods. Hatfield et al.
63 (1992), for example, had 12 trained runners complete a 36 min continuous run at an average
64 intensity of 71% VO_{2max} . The run consisted of three randomized segments during which
65 runners either 1) received concurrent biofeedback of minute ventilation (i.e., volume of air
66 breathed per minute; V_E) and electromyography (EMG) data of forearm and trapezius
67 muscles, 2) engaged in a distracting task, or 3) completed a control (no specific attentional
68 focus) condition. Outcomes included a reduction in V_E and respiratory frequency during
69 biofeedback, but no difference in VO_2 or EMG activity between conditions. The authors
70 suggested participants may already have had a ‘relaxed running style’ (p. 223) and acute
71 improvements RE may not have been possible (Hatfield et al., 1992).

72 The ability to improve RE with longer-term relaxation training has been
73 demonstrated, however. Caird, McKenzie, and Sleivert (1999) reported a large reduction in
74 VO_2 ($d = 0.85$), and a small-to-moderate reduction in heart rate ($d = 0.35$) at lactate threshold
75 intensity following six weeks of biofeedback, progressive muscular relaxation (PMR), and
76 centering training with seven trained distance runners. In addition, during the training period
77 VO_2 data were recorded during control (no biofeedback or centering) and biofeedback
78 conditions while running at an intensity equivalent to 70% of peak running velocity. Results
79 indicated that RE progressively improved with relaxation training, ranging from trivial during

80 the first trial ($d = 0.03$), to small-to-moderate during the sixth ($d = 0.33$), to moderate ($d =$
81 0.55) during the 12th intervention trial. Improvements in RE were independent of changes in
82 other physiological markers of aerobic performance (e.g., VO_{2max}) over the study period.

83 The findings from these laboratory-based studies suggest that relaxation-induced
84 improvements in RE may only be possible with longer-term training using sophisticated
85 psychological methods. Furthermore, relaxation training (e.g., PMR, centering, or breathing
86 techniques) as part of multimodal psychological skill interventions (i.e., also including self-
87 talk, imagery, etc.) has improved performance during 1600m running (Patrick & Hrycaiko,
88 1998) and simulated triathlon events (e.g., Thelwell & Greenlees, 2003). These skills may be
89 difficult to learn, however (e.g., Crews, 1992), and the specialist psychological support
90 required is often unavailable to most runners (McCormick, Meijen, & Marcora, 2016).
91 Consequently, whether relaxation cues can be effective as part of the brief contact
92 interventions accessible to the majority of athletes (e.g., online, at pre-race events; Lane et al.,
93 2016; Meijen, Day, & Hays, 2016) remains to be seen. Furthermore, which cues are most
94 effective to induce relaxation is unknown. In this regard, a common instruction to relax
95 runners' upper-body is to imagine 'holding a crisp [potato chip] between each thumb and
96 forefinger, tight enough to hold it without crushing it,' or to hold the fingers in a 'relaxed
97 clench position' (Murphy, 2009, p. 25). No research has determined the effects of these
98 attentional cues on RE, physiological, or perceptual responses during running, however.

99 Some studies have experimentally demonstrated an impact of other attentional focus
100 instructions on RE. Specifically, Schücker and colleagues evidenced a reduced RE when
101 runners were instructed to focus attention on highly automated processes such as breathing or
102 running movement in comparison with control conditions (e.g., Schücker, Knopf, Strauss, &
103 Hagemann, 2014). Similar effects have been observed with both trained and inexperienced
104 runners (Schücker et al., 2016). These findings further confound the use of relaxation during

105 endurance performance. Specifically, it suggests that instruction to focus on breathing to
 106 relax during activity (e.g., Thelwell & Greenlees, 2003) may be counterproductive and,
 107 paradoxically, increase the oxygen cost of running (Schücker et al., 2014, 2016).

108 In addition, few studies have investigated the effects of facial expression (e.g.,
 109 smiling, frowning) on physiological and perceptual responses during endurance activity.
 110 According to the facial feedback hypothesis (FFH), facial expression may influence one's
 111 emotional experience in a given situation (e.g., Tourangeau & Ellsworth, 1979). This concept
 112 embraces elements of embodied cognition; the notion that the body functions as a constituent
 113 of the mind and is directly involved in, and productive of, cognition (e.g., Shapiro, 2011).
 114 Specifically applied to emotional states (i.e., embodied emotion), manipulating the bodily
 115 expression of an emotion (e.g., facial expression) can influence how emotional information is
 116 processed and may be accompanied by self-reports of the corresponding emotion (e.g.,
 117 Niedenthal, 2007; Niedenthal, Mermillod, Maringer, & Hess, 2010). Thus, simulated
 118 frowning may prime unpleasant feelings (e.g., Larsen, Kasimatis, & Frey, 1992) and, in
 119 contrast to relaxation, increase activation and muscle tension which may, in turn, reduce RE
 120 (e.g., Martin, Craib, & Mitchell, 1995). Furthermore, frowning muscle activity, termed the
 121 'face of effort', has shown a moderate-to-strong positive relationship with effort perception
 122 during physical tasks (de Morree & Marcora, 2010). Encapsulating elements of embodiment
 123 concepts, de Morree and Marcora (2010) suggested this relationship may be bidirectional and
 124 exaggerated frowning – activated by contracting the corrugator supercilii muscles – may
 125 increase effort expended and/or perceived during a physical task.

126 In contrast to frowning, a facial expression of more positive emotions (e.g., smiling)
 127 may prime a more relaxed bodily state; reducing muscle activation, VO_2 , and effort
 128 perceived. Smiling during stress-inducing tasks, for example, has been shown to lower heart
 129 rate during recovery to a greater extent than a neutral facial expression (e.g., Kraft &

130 Pressman, 2012). Such responses may be most pronounced when individuals produce ‘real’
 131 or Duchenne smiles (Duchenne, 1990) that reflect positive emotions such as enjoyment (e.g.,
 132 Niedenthal et al., 2010). Duchenne smiles differ from non-Duchenne smiles (e.g., false or
 133 insincere smiles), or smiles with alternative functions (e.g., social affiliative smiles or
 134 dominance smiles), by symmetrical activation of the zygomaticus major (mouth movement)
 135 *and* activation of the orbicularis oculi (eye and cheek movement) muscles (e.g., Niedenthal et
 136 al., 2010; Rychlowska et al., 2017). Both Philippen, Bakker, Oudejans, and Canal-Bruland
 137 (2012) and McCormick, Meijen, Pageaux, and Marcora (2016) have investigated the effects
 138 of facial expression during physical exercise. Philippen et al. (2012) indicated that smiling
 139 may reduce effort perception and increase affective valence during moderate-intensity
 140 cycling in comparison with frowning. However, this study did not include a control condition
 141 and did not report the physiological responses to each expression. In contrast, McCormick et
 142 al. (2016) reported that frowning did not influence heart rate, affective state, or perceived
 143 effort when compared with thumb contraction and no intervention control conditions during a
 144 time-to-exhaustion cycling task. Given these contrasting findings, and anecdotal accounts of
 145 the use of smiling by endurance athletes (e.g., Fitzgerald, 2014), further investigation of the
 146 physiological and perceptual responses to manipulated facial expressions is warranted.

147 Accordingly, the aims of this study were to compare the effects of attentional focus
 148 cues to a) smile, b) frown, c) consciously relax, and d) engage normal thoughts (control
 149 condition) on RE (i.e., VO_2), physiological (i.e., heart rate), and perceptual responses during
 150 running. Secondary respiratory variables (e.g., carbon dioxide produced (VCO_2), respiratory
 151 frequency, V_E) were also analyzed to gain a deeper insight into the physiological effects of
 152 the attentional focus cues. Three main hypotheses were proposed. First, it was hypothesized
 153 (H_1) that RE would be improved (i.e., lower VO_2) and heart rate reduced during smiling in
 154 comparison with frowning and control. Second, given that conscious relaxation may require a

155 period of training (Caird et al., 1999) it was hypothesized (H_2) that VO_2 and heart rate would
 156 also be lower during smiling than relaxation. Thirdly, in line with the contentions of the FFH
 157 and embodied emotion, it was hypothesized (H_3) that effort perception and activation would
 158 be lower and affective valence more positive during smiling in comparison with frowning.

159 **Methods**

160 **Participants**

161 Research by Schücker and colleagues have reported moderate ($\eta_p^2 = 0.099$; Schücker
 162 et al., 2016) and large ($\eta_p^2 = 0.29$; Schücker et al., 2014) effect sizes for attentional focus
 163 manipulations on RE. For the present study, an a priori power analysis (Repeated Measures
 164 ANOVA, within factors) with a moderate effect size ($f = 0.25$), a power of 0.8, an alpha level
 165 of 0.05, a modest correlation between repeated measures ($r = 0.5$), and four measurements
 166 suggested a sample size of 24. This specific number allowed all possible randomized
 167 sequences of attentional focus cues (24 possible sequences) to be completed once during data
 168 collection. Consequently, 24 club-level endurance runners were recruited to participate. All
 169 participants were healthy, free from injury, were accustomed with treadmill running, and
 170 engaged in regular endurance running training. Specifically, all participants had previously
 171 completed a maximum race distance of at least one half-marathon ($n = 7$) or one marathon (n
 172 $= 17$), and currently ran on average 3.60 ($SD = 0.86$) days per week with a total running
 173 volume of 39.40 km ($SD = 15.64$) per week (see Table 1). Prior to recruitment all volunteers
 174 provided written informed consent and completed a medical history questionnaire to ensure
 175 no underlying medical conditions were present. The study was approved by the institutional
 176 research ethics committee and was conducted in accordance with the Declaration of Helsinki.

177 **Procedures**

178 The study consisted of two sessions for each participant. Each session was completed
179 at the same time of day (+/- 2 hours) and between 3-7 days apart to minimize fatigue.
180 Participants were asked to maintain normal activity, sleep patterns, and diet, and to avoid
181 strenuous exercise and excessive caffeine or alcohol consumption in the 24 hours before each
182 session. Participants were also asked to drink 500 ml of water (to ensure adequate hydration)
183 and avoid any food or caffeine consumption in the 2 hours before each session. Participants
184 were naïve to the experimental aims and hypotheses. Only when all data collection was
185 complete were participants fully debriefed on the nature and hypotheses of the study.

186 **Session one.** During session one, participants completed an incremental exercise test
187 to volitional exhaustion on a treadmill (h/p/cosmos quasar; h/p/cosmos Sports & Medical
188 GmbH, Traunstein, Germany) with continuous measurement of respiratory gas exchange
189 using an online metabolic cart calibrated before each test (Quark C-PET, Cosmed Srl, Rome,
190 Italy). Following a 5 min warm-up at a self-selected pace, participants began at a light
191 intensity based on their ability, with the intention of reaching volitional exhaustion within 10-
192 15 min. Stages during the test lasted 2 min, with 2 kph increments for each of the first three
193 stages followed by 1 kph increments to volitional exhaustion. Heart rate was measured
194 continuously by wireless telemetry (Polar RS400, Kempele, Finland). VO_{2max} was
195 determined as the highest value for a 10-breath rolling average and velocity at VO_{2max}
196 (vVO_{2max}) was determined as the lowest speed at which the plateau in VO_2 was evident (Hill
197 & Rowell, 1996). The treadmill incline was maintained at 0% throughout. Mean data for all
198 24 participants indicated that volitional exhaustion was reached in 11.71 min ($SD = 3.40$).

199 During the last 30 seconds of each of the first three stages, participants were asked to
200 indicate their perceived effort, affective valence, and activation (see subsection on *perceptual*
201 *responses*). This served to familiarize participants with each scale. Participants were also
202 informed that these were routine exercise laboratory measures. On completion of the VO_{2max}

203 test, participants were also asked to recount their attentional focus during the first three stages
 204 to indicate participants' 'normal' attentional focus during treadmill running in the laboratory
 205 environment (see *session two*). Thoughts were categorized using Brick et al.'s (2014)
 206 attentional focus categories. Specifically, these categories were *active self-regulation* (e.g.,
 207 relaxing, running technique, etc.), *internal sensory monitoring* (e.g., effort sensations,
 208 breathing, thirst, etc.), *outward monitoring* (e.g., split times, distance information, etc.), and
 209 both *active* and *involuntary distraction* (e.g., irrelevant daydreams, reflective thoughts, etc.).

210 **Session two.** Following an experimental design pioneered by Schücker and
 211 colleagues (e.g., Schücker et al., 2016), session two consisted of four blocks of 6 min runs
 212 with a 2 min passive rest interval between blocks. Because both oxygen consumption and
 213 heart rate were outcome variables, each run was performed at 70% vVO_{2max} , on a 0%
 214 gradient, an intensity equivalent to that used previously to study the effects of relaxation on
 215 RE (Caird et al., 1999). Before beginning, participants were informed about the testing
 216 protocol and equipped with a heart rate monitor and the Cosmed Quark system as per session
 217 one. Prior pilot testing assured that wearing the breathing mask did not interfere with the
 218 ability to adopt and maintain the required facial expressions. Experimenters were positioned
 219 out of the direct eye-line of participants. Neither heart rate nor respiratory data were visible to
 220 participants and the treadmill interface displays were obscured during session two to avoid
 221 providing biofeedback or other information. Participants completed a 5 min warm-up
 222 comprising 3 min at 50% vVO_{2max} followed by 2 min at 70% vVO_{2max} . Following a 2 min
 223 passive rest post warm-up, participants then began their first 6 min block of running.

224 Running blocks were randomized (using a computer random number generator) and
 225 each participant completed one block either smiling, frowning, consciously relaxing, or with
 226 a normal (control) attentional focus. Condition instructions were read by the first author from
 227 a script. General instructions were based on those implemented by Smith et al. (1995).

228 Specific cues for the smiling condition were adopted from Philippen et al. (2012) to
 229 encourage a real (Duchenne) smile. Before the smiling condition participants were instructed,
 230 *‘For this running block, please focusing on smiling. While several different types of smile*
 231 *exist, please focus on producing what you would consider a ‘real’ smile. Real smiles involve*
 232 *both one’s mouth and one’s eyes. Please monitor your facial expression and keep smiling’.*

233 Instructions during the frowning condition also incorporated cues from Philippen et
 234 al. (2012) and terminology from de Morree and Marcora (2010) (i.e., face of effort) to elicit
 235 each participant’s facial expression of effortful running. Accordingly, prior to the frowning
 236 condition, participants were read the following, *‘For this running block, please focus on*
 237 *frowning. A frown is produced when one brings the eyebrows together and down, and the*
 238 *eyes are narrowed to a slit. During running, you might consider this a face of intense effort.*
 239 *Please focus on producing what you would consider a ‘real’ frown or face of intense effort.*
 240 *Please monitor your facial expression and keep frowning’.*

241 Attentional instructions for the relaxation condition were based on cues to induce
 242 relaxation in the hands and upper-body (e.g., Murphy, 2009). Specifically, participants were
 243 instructed, *‘For this running block, please focus on your hands and upper-body, keeping your*
 244 *hands and upper-body as relaxed as possible while running with your normal gait. One cue*
 245 *might be to focus on touching your thumb and index finger together as lightly as possible as*
 246 *if you were holding a crisp and trying not to break it, or to hold your fingers in a relaxed*
 247 *position. Please monitor your hands and upper-body and keep them relaxed.’*

248 Finally, prior to the control condition participants were asked to focus on their
 249 ‘normal’ thoughts during running. Because of the context (i.e., laboratory-based), participants
 250 were reminded of the thoughts they self-reported during session one. Participants were
 251 instructed, *‘For this running block, please focus on those thoughts you would normally focus*
 252 *on during running. For example, during your VO_{2max} test you said you focused on [inserted*

253 each participant's most frequent thoughts during session one] *during the start and middle*
 254 *parts of that run. Please monitor your thoughts and focus on your normal thoughts during*
 255 *running.*' The data collected during session one suggested that the most frequent foci in each
 256 category were relaxing (58.33% of participants) and improving technique (45.83%) (*active*
 257 *self-regulation*), breathing (75%) and body movement/form (54.17%) (*internal sensory*
 258 *monitoring*), the treadmill (e.g., speed; 50%) and breathing apparatus (41.67%) (*outward*
 259 *monitoring*), and reflective thoughts (29.17%) and daydreaming (20.83%) (*distraction*).

260 During all conditions, a brief manipulation reminder (final sentence of each
 261 instruction) was read to all participants after every 60 seconds of running.

262 **Data Collection**

263 **Respiratory variables and heart rate.** Respiratory exchange variables (VO_2 , VCO_2),
 264 respiratory frequency, tidal volume, minute ventilation (V_E), respiratory quotient (ratio of
 265 $VCO_2:VO_2$), and heart rate were measured continuously throughout session two.

266 **Perceptual responses.** Immediately following completion of each block, participants
 267 were asked to rate their perceived effort (RPE 6-20 scale; Borg, 1982). Specifically, runners
 268 were asked to rate how hard, heavy, or strenuous they perceived each 6 min run to be
 269 (Pageaux, 2016). Points of reference were exercise-anchored for session two and participants
 270 were instructed that 'no exertion' (i.e., point 6) reflected no physical activity, and 'maximal
 271 exertion' (i.e., point 20) corresponded to the point of volitional exhaustion during the VO_{2max}
 272 test. As a measure of affective valence, participants were asked to report how good or bad
 273 they felt during each block using Hardy and Rejeski's (1989) 11-point Feeling Scale. Verbal
 274 anchors for positive affect are feeling *fairly good* (+1), *good* (+3), and *very good* (+5).
 275 Finally, for perceived activation, participants were asked to indicate how aroused or 'worked
 276 up' they felt using the 6-point Felt Arousal Scale (Svebak & Murgatroyd, 1985). This scale

277 ranges from *low arousal* (+1) to *high arousal* (+6). Each scale was projected on a screen 3.5
278 m in front of the treadmill and removed once participants responded.

279 **Manipulation check and attentional focus.** As a manipulation check, participants
280 rated their ability to maintain each attentional cue during each block. Participants responded
281 subjectively on a Likert-type scale with verbal anchors at 0% (*none of the time*), 50% (*half of*
282 *the time*), and 100% (*all of the time*). Finally, on completion of all blocks, participants were
283 asked to recount specific thoughts engaged during each block during a brief interview.

284 **Statistical Analyses**

285 Repeated Measures Analyses of Variance (RM-ANOVA) were conducted for each of
286 the primary dependent variables (VO₂, heart rate, perceived effort, affective valence, and
287 activation), for secondary respiratory variables, and for the manipulation check. Mean data
288 for minutes 4 – 6 (i.e., last 3 min of each condition) were averaged for cardiorespiratory
289 variables to ensure steady-state data only were analyzed. If assumptions of sphericity were
290 violated, the Greenhouse-Geisser correction was used to report analyses. Follow up analyses
291 were conducted using the Holm-Bonferroni sequential adjustment (Holm, 1979) where
292 significant *F* ratios were observed. Statistical significance was accepted as $p \leq .05$ (two-
293 tailed). To indicate the magnitude of differences between pairs of conditions, Cohen's *d*
294 (Cohen, 1988) effect sizes are reported where relevant. Effect sizes for RM-ANOVA
295 outcomes (partial η^2) are reported in Table 2. All analyses were conducted using the
296 Statistical Package for the Social Sciences (IBM Statistics 23.0; SPSS Inc., Chicago, IL).

297 **Results**

298 Mean and standard deviation (*SD*) data for all outcomes are presented in Table 2.
299 During running blocks (at 70% vVO_{2max}), mean percent of VO_{2max} during all conditions was

300 75.04% ($SD = 5.44\%$) and mean percent of heart rate maximum was 82.47% ($SD = 5.12\%$),
 301 both indicating vigorous intensity running (e.g., Norton, Norton, & Sadgrove, 2010).

302 **Running Economy.** RM-ANOVA revealed a difference in VO_2 between conditions,
 303 $F(3, 69) = 5.88, p = .001$. Mean VO_2 (Table 2 and Fig 1) was lower during smiling than
 304 frowning (Mean difference, $[MD] = -0.94$ ml/min/kg, $p = .006, d = -0.23$) and control ($MD =$
 305 -0.76 ml/min/kg, $p = .040, d = -0.19$). A small reduction in VO_2 was noted during smiling in
 306 comparison with relaxing ($MD = -0.74$ ml/min/kg, $d = -0.18$), but this did not reach statistical
 307 significance ($p = .080$). Fourteen participants (58.33%; four females) were most economical
 308 during smiling, five during frowning (20.83%; three females), and four during control
 309 (16.67%; three females). Only one participant (female) was most economical when relaxing.

310 **Heart Rate.** Due to an equipment malfunction with one participant, data were only
 311 available for 23 participants. No differences in heart rate were noted between conditions ($p =$
 312 $.231$). There was a significant order effect, however, $F(3, 66) = 27.63, p < .001, \eta_p^2 = 0.56$
 313 and small increases in heart rate were recorded on successive blocks (i.e., 1st to 2nd block,
 314 etc.). No order effects for block number were apparent for any other variable (all $p > .05$).

315 **Perceived effort.** RM-ANOVA revealed a difference in perceived effort between
 316 conditions, $F(3, 69) = 4.81, p = .004$. Perceived effort (Table 2) was higher when frowning
 317 than both smiling ($MD = 1.04, p = .012, d = 0.58$) and relaxing ($MD = 0.92, p = .045, d =$
 318 0.49). There were no differences between any other pairs of conditions (all $p > .05$).

319 **Affective valence and activation.** No difference in affective valence was noted
 320 between conditions ($p = .266$). There was a difference in activation, however (Table 2), F
 321 $(2.22, 51.07) = 7.28, p = .001$. Activation was higher during frowning than all other
 322 conditions; smiling ($MD = 0.79, p = .006, d = 0.71$), relaxing ($MD = 0.67, p = .032, d = 0.59$),
 323 and control ($MD = 0.69, p = .030, d = 0.61$).

324 **Secondary variables.** Secondary respiratory responses are also presented in Table 2.
 325 Of these, V_E was different between conditions $F(3, 69) = 2.79, p = .047$, but post hoc
 326 comparisons did not reveal a difference between any two conditions. VCO_2 was also different
 327 between conditions $F(2.39, 54.85) = 3.69, p = .025$, with a greater VCO_2 produced during
 328 frowning than smiling ($MD = 0.91$ ml/min/kg, $p = .030, d = 0.21$).

329 **Manipulation check and attentional focus.** The manipulation check revealed no
 330 difference in instruction adherence between conditions ($p = .312$). Manipulation adherence
 331 was high (>81%) across all conditions (see Table 2). A follow-up independent samples t-test
 332 also suggested no difference in adherence between genders during any condition (all $p > .05$)

333 The brief post-session interview revealed further insight into runners' thought content
 334 during each condition. During smiling, 17 participants (70.83%) engaged in pleasant thoughts
 335 (e.g., of family members, amusing events). Of these, 11 (64.71%) were most economical
 336 when smiling. Five runners (20.83%) reported only simulating the smiling expression and of
 337 these, three (60%) were most economical in this condition. When frowning, eight runners
 338 (33.33%) reported imagined effort-related sensations or simulating facial expressions of
 339 effort (e.g., as experienced during intense running). Eight other runners reported simulating
 340 frowning only and five runners (20.81%) reported engaging unpleasant thoughts (e.g., of
 341 political events). Of the five runners most economical when frowning, one reported a focus
 342 on sensations at the end of a marathon, another engaged unpleasant thoughts but deliberately
 343 attempted to stop these, and one found the expression difficult to maintain (60% adherence).

344 Eleven runners (45.83%) reported that they previously used the hands/upper-body
 345 relaxation cues during usual running (as instructed by a coach), including the one runner who
 346 was most economical in this condition. Two runners (8.33%) reported engaging additional
 347 thoughts to relax (e.g., repeating rhymes, counting breaths), but one runner did report
 348 excessive conscious control of the manipulation, despite doing this normally during running.

349 Finally, during the control condition, nine runners (37.50%) reported normal, irrelevant
350 distractive or reflective thoughts (e.g., daydreaming, work-related thoughts). However, six
351 (25%) reported difficulty engaging ‘normal’ thoughts in the unusual laboratory setting.

352 Discussion

353 The aims of this study were to compare the effects of brief contact attentional focus
354 cues to smile, frown, consciously relax the hands and upper-body, or engage normal thoughts
355 (control) on running economy (RE), physiological, and perceptual responses during running.
356 The first and second hypotheses, that RE would be improved and heart rate reduced during
357 smiling in comparison with the other conditions, were partially supported. Specifically, this is
358 the first study to demonstrate an improved RE (lower VO_2) during smiling in comparison
359 with frowning and participants ‘normal’ thoughts. In total, 14 of 24 participants (58.33%)
360 were most economical when smiling. Although the lower VO_2 during smiling in comparison
361 with relaxing did not reach statistical significance, only one participant was most economical
362 when consciously attempting to relax, despite 11 of 24 runners (45.83%) being familiar with
363 the relaxation cue. No differences in heart rate were noted between conditions, though an
364 order effect for block number was apparent. The third hypothesis, that effort perception and
365 activation would reduce and affective valence increase during smiling in comparison with
366 frowning, was also partially supported. Specifically, a second novel finding of the present
367 study was an increased effort perception during running when frowning in comparison with
368 smiling and relaxation conditions. No differences were noted for affective valence, though
369 perceived activation was higher when frowning than all other conditions.

370 Overall, smiling reduced the oxygen cost of running at a vigorous intensity by 0.94
371 ml/min/kg (2.78%) in comparison with frowning and by 0.76 ml/min/kg (2.23%) compared
372 with control. A greater volume of CO_2 was also produced when frowning than smiling (0.91
373 ml/min/kg; 2.91%). The improved RE is toward the lower end of the 2% to 8% reported for

374 short-term training modes (e.g., Moore, 2016) but is greater than the smallest worthwhile
 375 change for RE (2.2% to 2.6%) suggested by Saunders, Pyne, Telford, and Hawley (2004). As
 376 such, the improved RE can be considered a real and worthwhile change. Furthermore, the
 377 lower VO_2 when smiling is equivalent to the 2% to 3% improvement noted by Turner,
 378 Owings, and Schwane (2003) following six-weeks of plyometric training in distance runners,
 379 and the 1.7% to 2.1% observed by Barnes et al. (2013) after 13 weeks of heavy resistance
 380 training in male cross-country runners. Incorporating the facial feedback hypothesis (e.g.,
 381 Tourangeau & Ellsworth, 1979) and embodied emotion (e.g., Niedenthal, 2007), the
 382 improved RE suggests manipulated smiling (i.e., enjoyment smiles) may prime a more
 383 relaxed emotional state. In turn, this may reduce sympathetic nervous system activity, muscle
 384 activation, and tension (e.g., Williams et al., 1991), culminating in the lower VO_2 and VCO_2
 385 observed when smiling. Though heart rate did not differ between conditions, the order effect
 386 for block number (heart rate data only) suggests cardiovascular drift (CVD); the progressive
 387 increase in heart rate during constant workload exercise (e.g., Foss & Keteyian, 1998), may
 388 have had a greater influence on heart rate than the attentional manipulations. During running,
 389 CVD can be influenced by body temperature change (e.g., Buresh, Berg, & Noble, 2005)
 390 which may account for the heart rate data observed.

391 Differences in gender responses to smiling should also be noted. Of 13 male
 392 participants, 10 (76.92%) were most economical when smiling in comparison with only four
 393 of 11 females (36.36%). Previous studies have reported gender differences in perceptual
 394 responses during exercise. Most pertinently, Boutcher, Fleischer-Curtain, and Gines (1988)
 395 indicated that males reported lower effort perception in the presence of a female experimenter
 396 during cycle ergometry. Similar effects were not observed for female participants or in a
 397 same-gender experimenter condition. Boutcher et al. (1988) suggested their findings may be
 398 the result of opposite-gender concerns about self-presentation (e.g., social appropriateness, fit

399 to the social situation) and self-image. Relevant to the present study, a male experimenter
 400 requesting female participants to smile in an unfamiliar social setting may, inadvertently,
 401 have invoked concerns over self-presentation and self-image. Although no gender differences
 402 in manipulation adherence were reported, it is possible that some females may not have
 403 produced a ‘real’ or Duchenne smile. More expressive facial expressions are known to
 404 increase the intensity of emotional responses (e.g., Davis, Senghas, & Ochsner, 2009).
 405 Accordingly, non-Duchenne or less intense smiles, concerns over self-presentation, or both,
 406 may have reduced the efficacy of smiling as a relaxation cue for some study participants.

407 The lack of effect for the attentional cue to relax the hands and upper-body is in line
 408 with previous findings for brief contact interventions with runners (Smith et al., 1995) and
 409 research incorporating psychological methods such as biofeedback and PMR (e.g., Hatfield et
 410 al., 1992). It may be that longer-term training is required to reduce RE using cues to relax the
 411 hands and upper-body (e.g., Caird et al., 1999), particularly for runners who are not familiar
 412 with this attentional cue. It is noteworthy, however, that many participants reported using this
 413 cue previously during normal running, and 14 of 24 participants (58.33%) reported relaxing
 414 during session one (i.e., normal thoughts). Considering this, an additional explanation may be
 415 provided by the Multi-Action Plan Model (e.g., Bortoli, Bertollo, Hanin, & Robazza, 2012).
 416 Applied to endurance activity (e.g., Bertollo et al., 2015), this model suggests that an
 417 automatic attentional focus facilitates optimal performance for well-learned actions. In
 418 contrast, excessive monitoring and an over-controlled attentional focus (i.e., reinvestment;
 419 Masters & Maxwell, 2008) may disrupt automatic skill execution when individuals attempt to
 420 consciously control task performance. As such, participants familiar with the relaxation cue
 421 may control the relaxation process relatively automatically under normal circumstances.
 422 Increased conscious monitoring and control, as indicated by one study participant, may have
 423 disturbed automated processes and reduced the efficacy of the relaxation cues as a result.

424 In terms of perceptual responses, the increased effort perception when frowning in
 425 comparison with both smiling and relaxing is in agreement with the findings of Philippen et
 426 al. (2012) and offers some support for the suggestion of a bidirectional relationship between
 427 frowning and perceived effort (e.g., de Morree & Marcora, 2010). However, the similarity
 428 with McCormick et al. (2016) (i.e., no difference in perceptual responses when frowning in
 429 comparison with control), and the lack of difference between frowning and control conditions
 430 in the present study is also important to note. In this regard, data on the content of
 431 participants' thoughts during each condition may also be important to consider. Specifically,
 432 distractive (e.g., daydreaming) and active self-regulatory (e.g., relaxing) cognitions are
 433 known to reduce effort perceived during endurance activity (Brick et al., 2014). They may do
 434 so by competing with sensory cues regarding informational (e.g., intensity) and emotional
 435 (e.g., negative associations) components of effort, reducing perceptual awareness of these
 436 sensations as a result (e.g., Brewer & Buman, 2006; Brick et al., 2014). The lower effort
 437 perceived when focused on pleasant thoughts (i.e., when smiling) or one's hands and upper-
 438 body (i.e., when relaxing) support this contention. In contrast, frowning, via increased muscle
 439 activation and a focus on effort-related or unpleasant thoughts (e.g., Larsen, Kasimatis, &
 440 Frey, 1992), may elevate the intensity and/or negative emotional components of effort
 441 sensations, increasing effort perception as a result. As such, differences in effort perception
 442 noted in this study may reflect both a reduction (i.e., when smiling/relaxing) and an elevation
 443 (i.e., when frowning) in perceptual awareness of effort-related sensations during running.

444 Despite this, and in contrast to Philippen et al. (2012), the present study did not find a
 445 difference in affective valence between any conditions. Furthermore, during all conditions
 446 (Table 2), most runners generally reported a positive affective state. However, differences in
 447 activation were noted, and activation was higher when frowning than all other conditions.
 448 Applying the circumplex model of core affect (Russell, 2003), core affect was considered

449 low, but positive during smiling, relaxing, and control conditions. Specific emotional states
 450 associated with low positive affect include feeling calm and relaxed. The increased activation
 451 during frowning maintained a positive, but more activated affective state, one characterized
 452 by increased feelings of vigor and energy (e.g., Reed & Ones, 2006; Russell, 2003). As such,
 453 frowning may facilitate performance in some contexts by increasing activation. In support,
 454 Stanley, Lane, Devonport, and Beedie (2013) suggested that some individuals increase the
 455 intensity of emotions instrumentally – even unpleasant ones – if they are considered useful to
 456 goal attainment. Accordingly, upregulating positive activated affect before or during running
 457 (e.g., by frowning, or engaging arousing thoughts) may serve to increase vigor or effort
 458 expended on a task (de Morree & Marcora, 2010). The potentially negative impact on RE
 459 should be noted, however, and suggests that frowning should only be used as a regulatory
 460 strategy in a situationally-appropriate manner (e.g., Brick, MacIntyre & Campbell, 2015).

461 A number of limitations are apparent in the present study. Firstly, although
 462 participants were instructed to adopt specific facial expressions, the successful adoption of
 463 these could not be objectively ascertained. Due to constraints imposed by data collection (i.e.,
 464 wearing a breathing mask), activation of the zygomaticus major and orbicularis oculi
 465 (smiling), or corrugator supercilii (frowning) muscles could not be objectively measured.
 466 Although participants' subjective reports indicated acceptable manipulation adherence in all
 467 conditions (all > 81%), future objective measurement of facial expression using facial EMG
 468 (e.g., McCormick et al., 2016) or facial feature tracking (e.g., Miles, Clark, Periard, Goecke,
 469 & Thompson, 2017) may reveal further insight into the effectiveness of smiling during
 470 endurance activity. Expression duration may also be important to consider as adherence in
 471 this study (i.e., ~80% over 6 min) indicated that prolonged smiling may be both impractical
 472 and difficult to maintain. Accordingly, periodic or occasional smiling (as opposed to
 473 continuous smiling) may be most appropriate during sustained endurance activity.

474 Perceptual responses during experimental tasks may also be subject to demand effects
 475 (e.g., Zizzo, 2010) and the self-report nature of the scales used (e.g., feeling scale, RPE) may
 476 exacerbate this outcome. Specifically, participants may adapt responses based on cues about
 477 what constitutes an expected response. This may be particularly relevant for the ‘face of
 478 intense effort’ instruction during frowning and subsequent responses on the RPE scale. Many
 479 precautions were taken to ensure demand effects did not occur, however. Firstly, participants
 480 were naïve to the hypotheses of the study, and were informed that all perceptual scales were
 481 routine exercise laboratory measures during session one. Furthermore, similar to Philippen et
 482 al. (2012), physiological measures were of primary interest and perceptual responses
 483 secondary from participants’ perspective. Finally, it seems plausible that participants subject
 484 to demand effects may also indicate an altered affective valence during smiling (e.g., feel
 485 *very good*) and frowning (e.g., feel *bad*). As such, no difference in affective valence between
 486 conditions suggests these responses were unlikely to be influenced by demand effects.

487 Based on the findings of this study, future research is required to determine the
 488 effectiveness of smiling in real-world, ecologically valid contexts, and with athletes of a
 489 higher performance (e.g., elite) standard. This may provide support for the potential
 490 performance benefits accrued by improving RE with periodic smiling. In addition, objective
 491 measurement of expression intensity may reveal further insights into the effects of ‘real’
 492 smiling or frowning during endurance activity. Gender differences should also be explored to
 493 determine if experimenter influences, or alternative factors, account for the gender variations
 494 observed in this study. Finally, research on the effects of longer-term relaxation training,
 495 particularly with participants unfamiliar with attentional cues, may validate a focus on
 496 relaxing one’s hands and upper-body during endurance running.

497 This is the first study to experimentally investigate the effects of smiling, frowning,
 498 and relaxation cues on RE, heart rate, and perceptual responses during running. The novel

499 findings suggest that smiling may improve RE and reduce effort perception during running.
 500 In contrast, frowning may increase effort perceived and activation during endurance activity.
 501 An attentional cue to relax the hands and upper-body was not more efficacious on any
 502 outcome. As such, the efficacy of smiling to improve RE and lower effort perception suggests
 503 periodic smiling may be beneficial to enhance running performance and as brief contact cue
 504 for psychological interventions (e.g., Meijen et al., 2016) with endurance participants.

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Table 1

Demographic and training characteristics of study participants

Variable	Total (n = 24)	Men (n = 13)	Women (n = 11)
Age (Years)	44.59 (10.80)	41.65 (11.62)	48.08 (9.03)
Body Mass (kg)	70.50 (13.15)	77.02 (12.01)	62.79 (10.21)
Height (M)	1.67 (0.09)	1.74 (0.06)	1.59 (0.06)
VO _{2max} (ml/min/kg)	44.81 (5.65)	47.79 (5.09)	41.28 (4.15)
vVO _{2max} (kph)	14.79 (2.00)	16.15 (1.41)	13.18 (1.25)
Heart rate max (bpm)	177.83 (11.85)	179.15 (9.59)	176.27 (14.40)
Running experience (years)	4.14 (3.01)	4.49 (3.76)	3.72 (1.90)
Running frequency (sessions/week)	3.60 (0.86)	3.54 (0.83)	3.68 (0.93)
Running volume (km/week)	39.40 (15.64)	41.42 (13.32)	37.02 (18.39)

Note. Mean values and standard deviation (*SD*) for each demographic and training characteristic

Table 2

Outcomes for primary and secondary variables during each attentional focus condition

Measure	Smile	Frown	Relax	Control	<i>p</i>	Partial η^2
<i>Primary Variables</i>						
VO ₂ (ml/min/kg)	32.90 (4.05)	33.84 (3.99)	33.63 (3.89)	33.65 (4.18)	.001	0.20
Heart Rate ^a (bpm)	146.86 (14.46)	148.65 (14.41)	146.96 (16.02)	147.30 (13.84)	.231	0.06
Perceived Effort (AU)	11.25 (1.94)	12.29 (1.88)	11.38 (1.76)	11.63 (1.44)	.004	0.17
Affective Valence (AU)	2.58 (1.77)	1.96 (1.83)	2.50 (1.50)	2.54 (1.25)	.266	0.06
Activation (AU)	2.83 (0.96)	3.63 (1.13)	2.96 (1.12)	2.94 (1.20)	.001	0.24
Manipulation Check (%)	82.08 (16.41)	85.42 (13.51)	87.08 (8.59)	81.25 (16.50)	.312	0.05
<i>Secondary Variables</i>						
VCO ₂ (ml/min/kg)	31.16 (4.22)	32.07 (4.40)	31.58 (4.07)	31.73 (4.49)	.025	0.14
Respiratory Frequency (bpm)	38.80 (7.39)	38.55 (9.40)	36.58 (7.57)	36.62 (8.36)	.079	0.10
Tidal Volume (L)	1.75 (0.45)	1.83 (0.52)	1.84 (0.50)	1.86 (0.55)	.083	0.10
Minute Ventilation (L/min)	65.64 (13.35)	67.16 (13.02)	64.95 (12.82)	65.02 (13.30)	.047	0.11
Respiratory Quotient (AU)	0.95 (0.04)	0.95 (0.05)	0.94 (0.04)	0.94 (0.04)	.298	0.05

Note. Mean values and standard deviation (*SD*) for physiological data from the last 3 min of each 6 min block.
p-values and effect sizes (partial η^2) based on repeated measures ANOVA between conditions.

^aHeart rate data from 23 participants only.

AU: Arbitrary Units

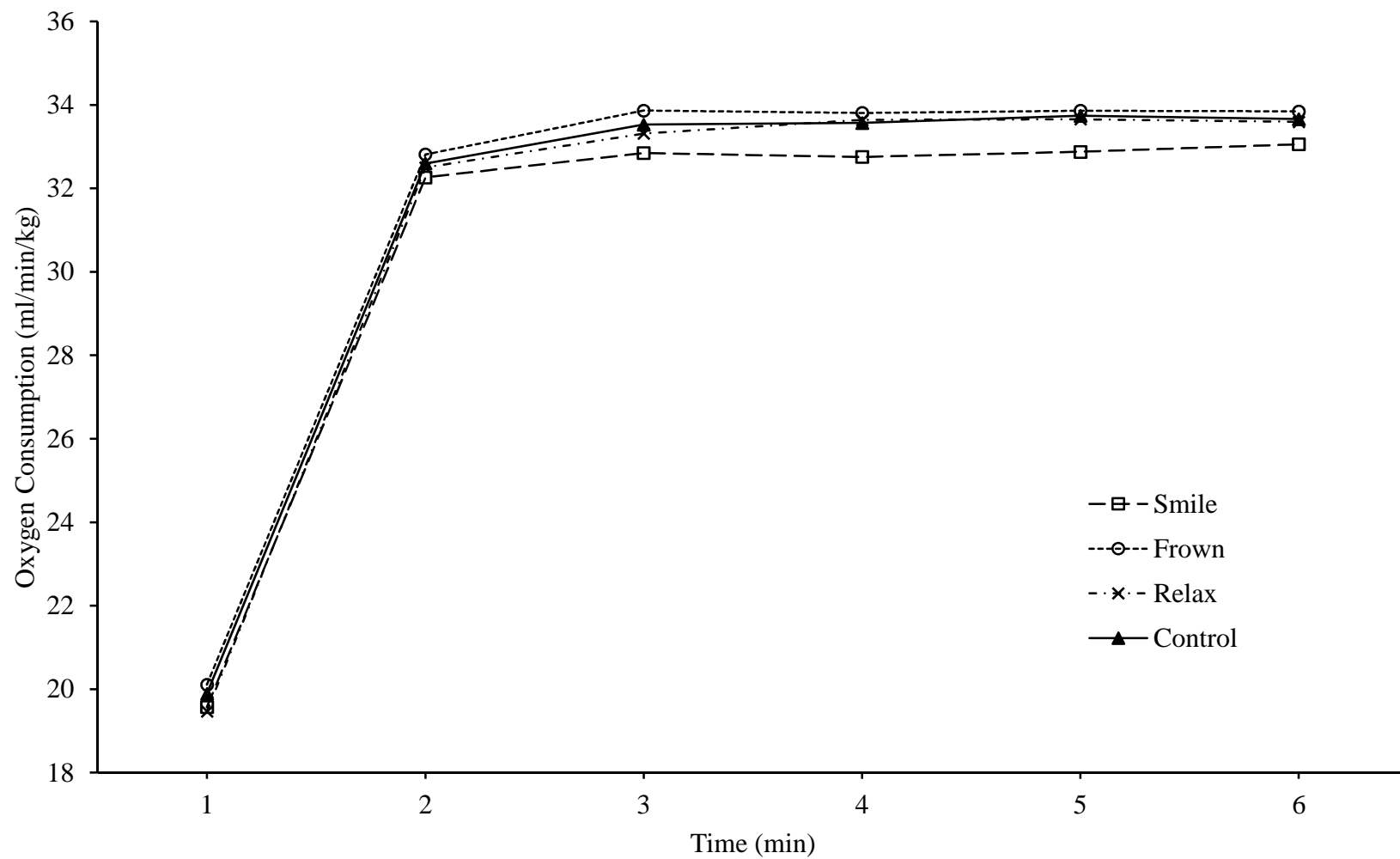


Fig. 1. Course of oxygen consumption for each condition (data represents mean value for each minute). Mean steady-state data inclusive of minutes 4 – 6 were included in the statistical analyses.

Highlights

Investigated the effects of smiling, frowning, and relaxation during running

Outcome measures included running economy, perceived effort, and affective state

Smiling improved running economy in comparison with frowning and a control trial

Perceived effort was higher when frowning in comparison with smiling and relaxing

Periodic smiling may be an effective attentional cue to enhance running performance