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Research article

Frowning and Jaw Clenching Muscle Activity Reflects the Perception of Effort During Incremental Workload Cycling

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Abstract
The present study aimed to investigate whether facial electromyography (EMG) recordings reflect the perception of effort and primary active lower limb muscle activity during incremental workload cycling. The effects of exercise intensity on EMG activity of the corrugator supercilii (CS), masseter and vastus lateralis (VL) muscles, heart rate (HR) and the rating of perceived exertion (RPE) were investigated, and the correlations among these parameters were determined. Eighteen males and 15 females performed continuous incremental workload cycling exercise until exhaustion. CS, masseter and VL muscle activities were continuously recorded using EMG during exercise. HR was also continuously monitored during the test. During the final 30 s of each stage of cycle ergometer exercise, participants were asked to report their feeling of exertion on the adult OMNI-Cycle RPE. HR and EMG activity of the facial muscles and the primary active lower limb muscle were strongly correlated with RPE; they increased with power output. Furthermore, facial muscle activity increased significantly during high-intensity exercise. Masseter muscle activity was strongly and positively correlated with HR, RPE and VL activity. The present investigation supports the view that facial EMG activity reflects the perception of effort. The jaw clenching facial expression can be considered an important factor for improving the reporting of perceived effort during high-intensity exercise in males and females.

Key words: Perceived exertion, facial electromyography, masseter muscle, corrugator supercilii muscle, incremental exercise testing.

Introduction

Evidence has suggested that the rating of perceived exertion (RPE) is correlated with various measurements of physiological processes, including cardiopulmonary factors [heart rate (HR), oxygen uptake (VO_2)] and peripheral factors (blood lactate and muscular strain) (Borg, 1982; Hampson et al., 2001). The functional link between RPE and physiological factors has been applied to exercise training and used in clinical settings. A sense of muscular strain is an important factor in the perception of effort (Robertson and Noble, 1997). Previously published studies have indicated that RPE is associated with active muscle strain, as measured using electromyography (EMG), during resistance training (Duncan et al., 2006; Lagally et al., 2002; 2004) and dynamic cycling exercise (Fontes et al., 2010; Macdonald et al., 2008). Furthermore, muscle activity, as measured using EMG, unrelated to the task, such as frowning, has also been shown to be associated with RPE (Blanchfield et al., 2014; de Morree and Marcora, 2010; 2012).

The face of effort is a type of facial expression that reflects how hard people are working during a physical task. The facial expressions often appearing as a frown or grimace reflect the subject's level of effort during a physical work task (Rejeski and Lowe, 1980). Specific facial expressions may convey physical effort, thereby contribute to an independent observers' estimate of an individual's momentary perception of exertion. Robertson et al. (2006) used changes in facial appearance (i.e. sweating, redness and grimacing) as one of the keys to observe and to rate exertion intensity. The procedure of observing exertion was that the observers were instructed to link increases in the subject's exertion with increases in facial redness and grimacing. Thus, the facial observation keys served as visual indicators of changes in the perception of exertion; these observation keys could visually aid in providing standard perceived exertion scaling procedures.

The facial expression of effort has been proposed as a method to predict and monitor exercise intensity, and it may provide an important non-verbal method to communicate the performance status of athletes (de Morree and Marcora, 2010). de Morree and Marcora (2010) first demonstrated that facial muscle activity associated with frowning was indicative of effort during physical tasks. In their study, the effect of workload (a progressive and systematic increase in workload) on EMG activity of the corrugator muscles increased concomitantly with overall RPE. In addition, they demonstrated a positive correlation between the perception of exertion and frowning muscle activity during leg extension exercise or aerobic exercise (de Morree and Marcora, 2010; 2012).

It is somewhat common for people to clench their teeth (jaw) while exerting maximal muscular effort during tasks such as lifting a heavy weight or participating in a sport that requires maximum effort (Ebben, 2006; Wallman and Sacco, 2007). Several studies have indicated a possible correlation between muscle activity associated with oral motor function and somatic motor function in other parts of the body (Ebben et al., 2008a; Kimura et al., 2007; Miyahara et al., 1996; Takada et al., 2000). Jaw clenching augments leg extensor force production and countermovement jumps, which could be associated with effort (Ebben et al., 2008b). According to these studies, jaw clenching activity may correlate with the perception of effort as well as frowning activity, which is one of the

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hypotheses investigated in the present study.

A positive correlation between RPE and frowning expression involving EMG evidence of facial muscle activity during leg extension and constant workload cycling exercises has been shown (de Morree and Marcora, 2010; 2012). However, this relationship has not been examined during incremental workload cycling exercise. In addition, jaw clenching activity has not been validated as being correlated to perceived exertion during aerobic exercise. Furthermore, it is not known which facial muscle activity is a good indicator of effort.

The aims of the present study were (i) to examine the effect of exercise intensity on EMG activity of two facial muscles and to examine whether EMG activity reflects the perception of effort as well as involved muscle activity during incremental workload cycling exercise and (ii) to determine the correlations between EMG activity of corrugator supercilii (CS) muscle (associated with frowning), that of the masseter muscle (associated with chewing), that of the vastus lateralis (VL) muscle, HR and RPE during incremental workload cycling exercise.

Methods

Subjects

Thirty-three volunteers, including 18 males (age: 22 ± 2 years; height: 1.73 ± 0.06 m; weight: 67 ± 7 kg) and 15 females (age: 22 ± 2 years; height: 1.61 ± 0.05 m; weight: 51 ± 6 kg), were recruited from a university population to participate in the study. All participants reported being moderately physically active (leisurely exercise at least twice a week), healthy and asymptomatic of illness and having no pre-existing injuries. Written informed consent was obtained from all participants, and the study purpose (but not the purpose of the facial electrodes) and protocol were explained to them. The experimental procedures were approved by the Institutional Review Board of Chang Gung Medical Foundation.

Procedures

Each participant performed an incremental workload exercise protocol on an electromagnetically braked cycle ergometer (Corival 906900, Lode BV, Groningen, The Netherlands). This incremental workload exercise allowed our hypotheses to be tested over a wide range of exercise intensities. Exercise included a 5-min warm-up at 0 watts (W), followed by a continuous and incremental increase in workload (starting at 40 W) by 40 W every 3-min. Participants were instructed to maintain a cycling cadence between 60 and 70 rpm by watching the digital signal of the cycle ergometer control panel throughout the exercise test. When a participant reached exhaustion or the inability to sustain a target pedal cadence greater than 55 rpm for a period of 5 s, the exercise test was terminated.

The subject's HR was continuously monitored during exercise by a wireless chest strap telemetry system (Polar Wear Link System and Polar FT4 HR monitor, Polar Electro Oy, Kempele, Finland). During the final 30 s of each 3-min stage of cycle ergometer exercise, participants were asked to report their overall feeling of exertion on the adult OMNI-Cycle RPE (Robertson et al., 2004). Perceived exertion was defined as the subjective intensity of effort. All participants did not have previous experience in the use of a category rating scale of perceived exertion. Chen et al. (2013) showed that the familiarity of participants regarding the use of the RPE scale did not affect the scores. Before the experiment, all subjects were well instructed regarding the use of the scale and OMNI RPE (Robertson et al., 2004). Because there is no validated Chinese-translated version of the OMNI scale, a verbal description of the OMNI scale was shown both in Chinese and English. Although the anticipation of subsequent workload stages during the incremental test could potentially be a confounding factor of perceived exertion, Coquart et al. (2009) and Skinner et al. (1973) noted that the perceptually based values were not significantly different between the incremental test and a test with randomised workloads. Thus, this suggests that cyclists were able to perceive differences in intensity on a cycle ergometer that were not influenced by demand bias. Activities of the CS, masseter and VL muscles were continuously recorded using EMG during exercise.

All participants were given written instructions to avoid intense exercise, caffeine and alcohol consumption during the 24 h preceding the test. In addition, they were asked to sleep for at least 7 h before the test and consume a light meal approximately 2 h before the test.

EMG recordings

During the exercise test, the surface EMGs of the VL muscle (a primary active leg muscle) and the CS and masseter muscles (both facial muscles) were measured. Disposable Ag/AgCI circular bipolar electrodes (Medi-Trace 200 series, Kendall-LTP, Chicopee, MA, USA) were used to measure VL muscle activity from the participants' dominant lower limb, which was determined by asking the subject which leg he or she would use to kick a soccer ball (Zeller et al., 2003). The electrodes (10 mm in diameter) were positioned on the skin using an adhesive conducting gel with an inter-electrode distance of 20 mm (centre to centre). The electrodes were placed approximately 3–5 cm above the patella on an oblique angle just lateral to the midline (Cram et al., 2011). Both facial muscles required small bipolar electrodes (Medi-Trace series 100, Kendall-LTP, Chicopee, MA, USA) that were positioned on the skin with an inter-electrode distance of 10 mm (centre to centre). To record CS activity, the electrodes were placed on one side of the face to directly observe frowning and grimacing facial activity on the other side of the subject's face. The facial EMGs were measured on the left side because emotions are expressed more intensely on the left side of the face (Sackeim et al., 1978). An electrode was placed superior to the eyebrow just lateral to the midline at a slight oblique angle (Cram et al., 2011). Two active electrodes, approximately 2 cm apart, were placed along the direction of the masseter muscle fibres. The area was palpated while the participant was asked to clench his or her teeth to facilitate the identification of the muscle belly. Electrodes were placed over the muscle belly (Cram et al., 2011). Prior to electrode placement on the skin, the area was shaved and cleaned with alcohol. The reference electrode was placed over the pisiform bone on one hand. To avoid bias from mimicry effects on facial EMG measurements, the experimenter stood behind participants and remained silent during data collection (Tassinary et al., 2007).

Surface EMG signals were amplified by the NeXus-10 system (Mind Media, The Netherlands). Signals were acquired at 1024 samples per second, bandpass filtered (20–500 Hz; IIR filter, Butterworth 4th order) and sent via bluetooth to a laptop for data visualisation, storage and pre-processing (BioTrace Software, Mind Media, The Netherlands). EMG amplitudes were calculated (root mean square, epoch size: 1/16 s, 32 samples per second). The raw EMG values were normalised against a reference voluntary contraction (RVC) and presented as a percentage (O'Leary et al., 2011) for each muscle. Normalised EMG (NEMG) values were obtained using the following equation:

$$\%RVC = (EMG_{measured} - EMG_{rest})/(EMG_{reference} - EMG_{rest}) \times 100\%$$

%RVC is the normalised EMG value, $EMG_{measured}$ is the measured EMG value, $EMG_{reference}$ is the EMG value obtained under maximal contraction during incremental workload exercise and EMG_{rest} is the EMG value obtained at rest.

Data processing

The NEMG data were analysed between 0.5 and 2.5 min of each stage during incremental workload exercise. Eighteen males reached a power output of 200 W, and 8 of them became exhausted at this stage; 10 males reached an output of 240 W, and 8 of them became exhausted at this stage. Only 2 males reached a power output of 280 W and became exhausted. Fifteen females reached an output of 120 W, and 11 of them became exhausted at this stage; 4 females reached an output of 160 W, and 2 of them became exhausted at this stage. Only 2 females reached a power output of 200 W and became exhausted. Because only smaller numbers of subjects reached 280 W (males) and 160 W (females), subsequent analyses did not include the higher stages. The data were analysed for power outputs of 40 W–240 W (Stages 1–6) for males and 40 W–120 W (Stages 1–3) for females. The HR and RPE data were collected during the last 30 s of each stage.

Statistical analyses

Differences in lower limb and facial muscle NEMG values, HR and RPE between the incremental workload stages (five stages for males and three stages for females) were tested by one-way repeated measures analysis of variance (ANOVA). The Bonferroni post hoc test was performed when any significant effects were found. To account for the lower number of male participants during the final stage, the remaining data from Stages 5–6 were subsequently analysed using separate one-way repeated measures. The exercise intensity effects and comparisons with lower limb NEMG value and facial NEMG values at the stage of exhaustion for both genders were made using Kruskal–Wallis non-parametric ANOVA, followed by the Dunn's post hoc test.

The within-subject correlation coefficients among the lower limb and facial muscle NEMG values, HR and RPE were examined using the method described by (Bland and Altman, 1995). Significance was set at a *p* value of 0.05 (two-sided) for all analyses. All analyses were conducted using the Statistical Package for Social Sciences Version 19 (SPSS Inc., Chicago, IL, USA).

Results

One-way repeated measures ANOVA, performed on the data from the first five stages for the 18 males, revealed that there were significant increases in HR ($F_{4,68} = 818.8$, $p < 0.001$), RPE ($F_{4,68} = 144.7$, $p < 0.001$), VL activity ($F_{4,68} = 173.3$, $p < 0.001$), masseter activity ($F_{4,68} = 36.4$, $p < 0.001$) and CS activity ($F_{4,68} = 5.5$, $p = 0.013$) as workload increased. Bonferroni's post hoc analysis revealed that HR, RPE and VL activity significantly and progressively increased as exercise intensity increased from one stage to the next among the five stages of exercise. The facial NEMG values of the masseter muscle were significantly greater at a workload of 200 W compared with those at the other four power outputs; however, they were not significantly different between 160 W and 120 W or between 80 W and 40 W. CS muscle activity was only significantly greater at a workload of 200 W compared with 80 W. To account for male subjects reaching maximal volitional exhaustion at different stages of the exercise test, the separated one-way repeated measures ANOVAs were used to examine the data only for participants who reached 240 W. This allowed examination of a wide range of the physiological and perceptual data collected. There were significant increases in HR ($F_{5,45} = 335.1$, $p < 0.001$), RPE ($F_{5,45} = 136.5$, $p < 0.001$), VL activity ($F_{5,45} = 143.6$, $p < 0.001$), masseter activity ($F_{5,45} = 20.1$, $p < 0.001$) and CS activity ($F_{5,45} = 3.7$, $p = 0.03$) as workload increased. Bonferroni's post hoc analysis revealed that HR, RPE and VL activity significantly and progressively increased as exercise intensity increased from one stage to the next among the six stages of exercise. Masseter muscle activity was significantly greater at a workload of 240 W compared with that at the other five power outputs; moreover, the activity was also significantly different between 200 W and 80 W, between 200 W and 40 W and between 160 W and 40 W. CS muscle activity was not significantly different between each stage. Figure 1 shows the increasing trend of the masseter, CS and VL activities and RPE and HR with incremental workload exercise in males.

The result of one-way repeated measures ANOVA for females also showed a main effect of exercise intensity on HR ($F_{2,28} = 110.2$, $p < 0.001$), RPE ($F_{2,28} = 144.7$, $p < 0.001$), VL activity ($F_{2,28} = 173.3$, $p < 0.001$), masseter activity ($F_{2,28} = 36.4$, $p < 0.001$) and CS activity ($F_{2,28} = 5.5$, $p = 0.009$). Bonferroni's post hoc analysis revealed that HR, RPE and VL activity significantly and progressively increased as exercise intensity increased from one stage to the next among the three stages of exercise. NEMG values of the masseter and CS muscles were significantly greater at 120 W than at 40 W and at 120 W than at 80 W; however, there was no significant difference between 80 W and 40 W. Figure 2 shows the increasing trend of masseter, CS, VL activity, RPE and HR with incremental workload exercise in females.

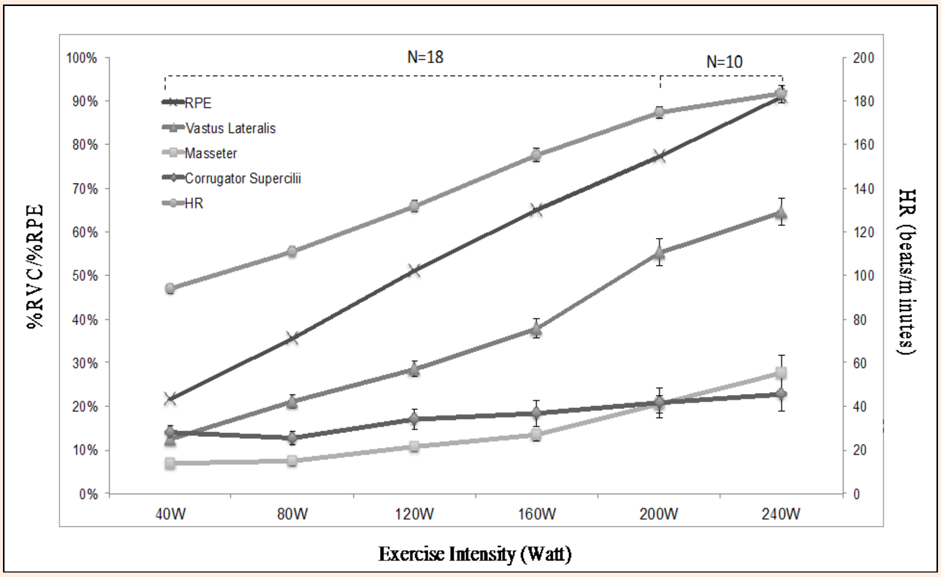

Figure 1. **Effects of exercise intensity on heart rate (HR), overall body rating of perceived exertion (RPE), lower limb normalised electromyographic (NEMG) value and facial NEMG value during incremental workload exercise in males.**

Table 1 shows the effects of exercise intensity on lower limb NEMG values and the two different facial NEMG values of participants just before exhaustion for both genders. For males, the Kruskal–Wallis one-way ANOVA with the Dunn's test showed that NEMG values of the masseter and the VL before exhaustion were significantly different compared with those at each lower power output stage. However, NEMG values of the CS muscle showed a significant main effect of exercise intensity, but there was no significant difference between post hoc comparisons. For females, the three NEMG values were significantly different compared with those at the first and second power output stages but were not significantly different between the first two stages.

Significant positive relationships were found between the following parameters for both males and females: lower limb NEMG values and HR, lower limb NEMG values and RPE and lower limb NEMG values and both facial NEMG values. Both facial NEMG values were also positively correlated with HR and RPE, with the exception of the NEMG value of the CS muscle and RPE for females. The two facial muscles were analysed separately. The within-subjects correlation coefficients are presented in Table 2.

Discussion

The main finding of the present study is the significant effect of power output on facial EMG, RPE, HR and lower limb EMG activity during continuous incremental

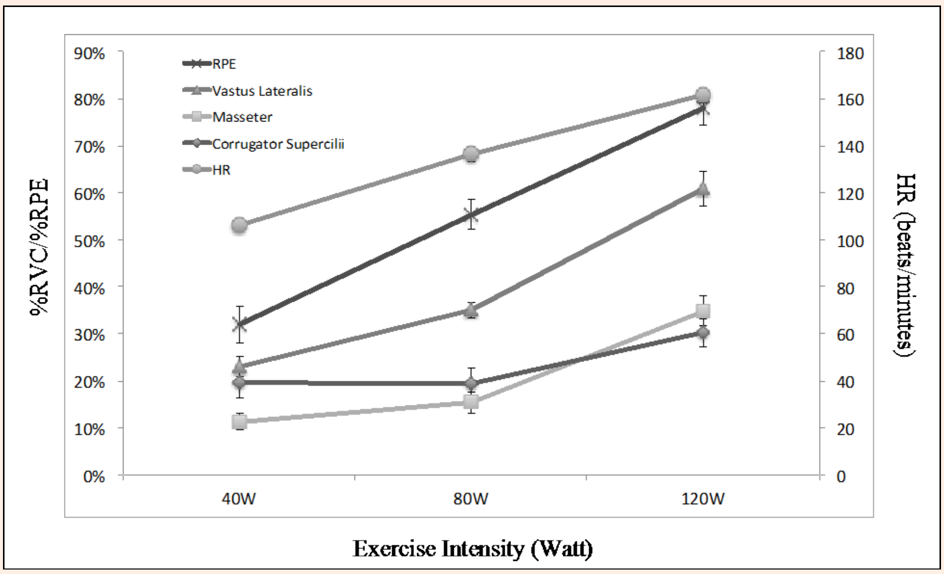

Figure 2. **Effects of exercise intensity on heart rate (HR), overall body rating of perceived exertion (RPE), lower limb normalised electromyographic (NEMG) value and facial NEMG value during incremental workload exercise in females.**

Table 1. Effects of exercise intensity on lower limb normalised electromyographic (NEMG) values and facial NEMG values at the exhaustion stage in both genders.

Male	**Power output of the exhausted stage**	200 W	240 W	280 W
	No. of reached	n = 18	n = 10	n = 2
	No. of exhaustion	n = 8	n = 8	n = 2
	CS	Non-significant	Non-significant	Non-significant
	Masseter	160 > 40*†, 200 > 40‡, 160 > 80†, 200 > 80‡, 200 > 120†	160 > 40†, 200 > 40‡, 240 > 40 ‡, 200 > 80‡, 240 > 80†, 200 > 120†, 40 > 120‡, 240 > 160†	Non-significant
	VL	120 > 40†, 160 > 40‡, 200 > 40‡, 160 > 80†, 200 > 80‡, 200 > 120†	160 > 40‡, 200 > 40‡, 240 > 40‡, 160 > 80†, 200 > 80‡, 240 > 80‡, 200 > 120‡, 240 > 120‡, 240 > 160†	Non-significant
Female	**Power output**	120 W	160 W	200 W
	No. of reached	n = 15	n = 4	n = 2
	No. of Exhaustion	n = 11	n = 2	n = 2
	CS	120 > 40†, 120 > 80‡	Non-significant	Non-significant
	Masseter	120 > 40†, 120 > 80‡	Non-significant	Non-significant
	VL	120 > 40†, 120 > 80‡	Non-significant	Non-significant

*: Watt; †: $p < 0.05$; ‡: $p < 0.01$; CS = corrugator supercilii; VL = vastus lateralis

workload cycling. Masseter muscle activity was strongly and positively correlated with effort perception and production.

Effect of exercise intensity on RPE, HR and facial and lower limb EMG activity

The present study demonstrated that VL NEMG activity and HR were strongly correlated with RPE and increased with power output during incremental workload cycling. These results are consistent with previous studies that have shown positively correlated increases in RPE and lower limb EMG activity (Macdonald et al., 2008; Perry et al., 2001) and in RPE and HR (Borg et al., 1987; Robertson et al., 2004). A feed-forward neurophysiological mechanism could explain the relationship between RPE and lower limb EMG activity (Lagally et al., 2002). The perception of effort is centrally generated by feed-forward neural signals (Marcora, 2009; Smirmaul, 2012). As exercise intensity increases, the number of central motor feed-forward commands required to increase motor unit recruitment and firing frequency in peripheral muscle also increase. Corollary discharges diverge from the descending motor commands and are sent to the sensory cortex, evoking perceptual signals of exertion that are consciously monitored. The greater the frequency of the corollary signals the more intense the perceived physical exertion.

Increased power output is also associated with an increase in facial EMG activity. It has previously been demonstrated that workload can affect EMG activity of the CS muscle during leg extension exercise (de Morree and Marcora, 2010) and constant workload cycling (de Morree and Marcora, 2012). In comparison with previously published studies, the current paper also examined incremental workload and included the masseter facial muscle. We found that increasing CS and masseter EMG activity coincided with VL muscle activity. The physiological link between the EMG signal and facial musculature as the intensity of leg exercise increases is that the EMG responses arising from the facial muscles are activated when an individual frowns or grimaces during high-intensity exercise. A central feed-forward neurophysiological mechanism may explain the relationship between RPE and lower limb EMG activity (Lagally et al., 2002). The significant correlation between RPE and facial muscle activation reported in the study by de Morree and Marcora (2012) and our study might indirectly result from the feed-forward motor command linked to an increase in facial muscle activation that is expressed by a grimace or frown. The increase in facial EMG activity with increased effort may be a result of motor overflow (de Morree and Marcora, 2010; van Boxtel and Jessurun, 1993). Motor overflow refers to the involuntary movement accompanying the production of a voluntary movement (Hoy et al., 2004). This phenomenon often presents under effort-induced conditions in young adults (Addamo et al., 2007; Hoy et al., 2004). The primary motor cortex motor area contains functional subdivisions of the face, arms and legs that are responsible for the control of muscle force. These divisions are overlapping and interconnected and thus could produce motor overflow (Donoghue and Sanes, 1994). Therefore, the spreading of activation in these cortex areas stimulates not only the active muscle involved in the task but also task-irrelevant muscles (Hoy et al., 2004) such as the facial muscles.

RPE, HR and lower limb EMG activity were all significantly different and demonstrated uniform increases among all stages, unlike facial EMG activity. The facial muscles of the CS (associated with frowning) and the masseter contracted significantly but only at high power

Table 2. Within-subject correlation coefficients for rating of perceived exertion (RPE), heart rate (HR), facial normalised electromyographic (NEMG) values and lower limb NEMG values.

	Male			Female		
	HR (beats·min^{-1})	RPE	VL muscle (%)	HR (beats·min^{-1})	RPE	VL muscle (%)
CS muscle (%)	.414‡	.268†	.375‡	.372‡	0.186	.494‡
Masseter muscle (%)	.893‡	.716‡	.794‡	.856‡	.849‡	.754‡
VL muscle (%)	.740‡	.753‡		.750‡	.742‡	

†: $p < 0.05$; ‡: $p < 0.01$; CS = corrugator supercilii; VL = vastus lateralis

outputs such at the stage of exhaustion for both males and females. The current results suggest that facial muscle EMG activity is more sensitive to higher intensity exercise levels. In agreement with the findings of de Morree and Marcora (2012), facial EMG activity increased only during high-intensity exercise. The phenomenon of motor overflow, which is usually seen only under conditions of increased effort and fatigue during voluntary contractions in healthy adults (Addamo et al., 2007; Hoy et al., 2004), may explain this observation and also why facial EMG activity did not increase significantly during the lower intensity stages.

Comparisons between CS and masseter EMG activity

Masseter EMG activity was associated with HR, RPE and VL EMG activity to a greater extent than CS EMG activity in the current study. This may be explained by the presence of functional associations between oral motor function (masseter muscle) and somatic motor function (lower limb muscle). Remote facilitations in the direction of the masseter muscle to the soleus (Miyahara et al., 1996) and pretibial (Takada et al., 2000) muscles of the lower leg have been shown to be induced by voluntary jaw clenching. The H reflexes in both the pretibial and soleus muscles are facilitated in association with voluntary jaw clenching (Miyahara et al., 1996; Takada et al., 2000). These results show that oral motor activity could exert strong influences on the motor activity of other parts of the body. Ebben et al. (2008b) demonstrated that jaw clenching improved force production in the lower limb extensor muscles. The masseter muscle can have a direct and positive relationship with activity of specific leg muscles and effort production that can be also explained by theories of motor overflow (Ebben et al., 2008b; Kimura et al., 2007; Miyahara et al., 1996; Takada et al., 2000). These results suggest that the masseter muscle is more directly associated with effort production by the lower limb compared with the CS muscle. Further research is needed to confirm that muscle activity associated with jaw clenching and frowning correlates with effort during other aerobic exercises.

Our findings confirm a relationship between the facial expression of effort and physical effort. The EMG responses are consistent with a neurosensory pathway involving feed-forward motor commands to the facial musculature. As such, it is suggested that the sensory–physiological link between descending motor commands (such as EMG) to the facial musculature and observable exertion cues, such as frowning and grimacing, are one of the central themes of our study. The inclusion of detailed examples of associated facial expression and perceived effort during high-intensity exercise may help determine the underlying mechanisms. Facial expressions associated with increased effort may be another way of predicting and monitoring exercise intensity. The facial expression of effort may also provide the observer with an estimate of the intensity of effort during physical activity. In particular, jaw clenching activity could be considered an important factor for assessing exertion.

Practical implications

There are many RPE scales specific to children (Eston et al., 2000; Robertson et al., 2000) and adults (Robertson, 2004), which include numbers, understandable verbal descriptors and pictorial cues to help explain the RPE scale. These pictorial cues mostly depict a character at various stages of exertion ascending a vertical numerical scale. The facial EMG data may assist in determining the intensity of pictorial cues in an RPE scale as well as the detail of facial expressions.

Potential limitations

There are some potential limitations of our study. First, participants may not be physically active, particularly the female subjects, and we did not rigidly define the criteria of being physically active such as exercise type, frequency and length when we recruited subjects. Furthermore, because each gender had different exercise capacity, it may be necessary to use different power output increments in the separate test protocols for the male and female subjects. Increments of 40 W every 3 min may be too high for female participants in the present study. Second, participants did not perform a maximal test or cycle under individualised exercise intensities. Thus, there may have been possible bias of inter-individual differences in peak aerobic power that occur when comparisons were made for the data obtained at fixed sub-maximal power output stages. Therefore, the measurement time point could be based on a priori determined percentage of total elapsed time or total work performed for each subject. This could be a design feature to be employed in future research. Third, there is a potential problem associated with the periods of data measurement. RPE was used as a measure during the last 30 s of each exercise stage to reflect complete workload. The EMG data was only selected during the period of 0.5–2.5 min of each stage to avoid possible artifacts in power output changes affecting the facial EMG during the first 30 s and avoiding facial muscle crosstalk during the last 30 s. However, the HR data should be better measured during the same period as that for the EMG data. Finally, there is a possibility that the masseter EMG contains EMG from other muscles, such as the neck muscles, because of muscle crosstalk. Better electrode placements could minimise any crosstalk. It is likely that our electrode positions were palpated well while the participant was asked to clench his or her teeth to facilitate the identification of the muscle belly. However, detecting a crosstalk signal may be reduced considerably by placing the electrode in the midline of the muscle belly. A double differential technique to eliminate possible crosstalk detected with surface EMG could also be applied (Huang et al., 2004).

Conclusion

Facial EMG activity reflected the perception of effort. Facial EMG activity, RPE, HR and lower limb EMG activity increased with power output during incremental workload cycling. The EMG responses were generated from the facial muscles that were activated when an individual frowned or grimaced during high-intensity exercise. EMG activity of the masseter muscle was strongly and positively correlated with RPE, HR and lower limb EMG activity during incremental workload cycling. The jaw clenching facial expression can thus be considered an important factor that determines the perception of effort and estimates the intensity of effort in both males and females during exercise.

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Key points

- Frowning and jaw clenching muscle activity reflects the perception of effort during incremental workload cycling.
- EMG activity of the masseter muscle was strongly and positively correlated with RPE, HR and lower limb EMG activity during incremental workload cycling.
- The jaw clenching facial expression can be considered an important factor for estimating the intensity of effort.

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