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Cold temperature does not affect perceived exertion in males and females during submaximal cycling

Adele Gandy[1], Marianne F Baird[1], Gary W Boyd[2], Chris Connaboy[3], Scott M Graham[1]*

1 *School of Applied Sciences, Edinburgh Napier University, Edinburgh, United Kingdom*
2 *School of Science and Sport, University of the West of Scotland, Paisley, United Kingdom*
3 *School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh USA*

Abstract

Background: Perceived exertion is an acknowledged indicator of exercise intensity and homeostasis disturbance of an individual, however, there are few studies that have examined the influence of cold temperatures on perceived exertion measurements. Cognition is crucial to perception and exposure to cold temperatures can elicit decrements in cognition. **Aims & Objectives:** The aim of this study was to determine if, and to what extent, exposure to cold environments may influence perceived exertion and cognitive ability. **Study Design:** Randomised controlled trial. **Materials & Methods:** Sixteen participants (m= 8, f= 8, age: 22.3 ± 1.7 years (mean ± SD)), completed two trials in a randomised order in COLD (5°C) and CONTROL (18 °C, 55% relative humidity) conditions. During each trial, following a standardised warm up, participants performed a 6-minute cycle ergometer submaximal exercise. Cognitive ability was assessed pre and post exercise with a reaction time (RT) test. Participant's physiological responses were measured using Rate of Perceived Exertion (RPE), Heart Rate (HR), Oxygen consumption (VO_2), Minute Ventilation (V_E), Tympanic (T_t) and Skin Temperature (T_{sk}) continuously during testing. **Statistics:** Two-way repeated measures Analysis of Variances (ANOVA), were between environmental conditions over time. Data are reported as mean (*M*) ± standard deviation (*SD)*. Ordinal Friedman ANOVA tests were conducted on RPE data between environmental conditions and gender. Non-parametric descriptive statistics were reported as medians (*Mdn*) and inter-quartile ranges (*IQR*) (25^{th} – 75^{th} Percentile). Statistical significance was accepted at $p < 0.05$. **Results:** There was no significant difference ($p > 0.05$) reported in RPE, VO_2 and V_E between COLD and CONTROL groups, however, significant decreases in T_{sk} ($p = 0.001$) and T_t ($p = 0.001$) were observed in COLD compared to CONTROL groups. Additionally, no significant differences ($p > 0.05$) in RT occurred between COLD and CONTROL. Furthermore, no significant differences in RPE were established between genders. **Conclusions:** Short-term exposure to cold temperatures does not significantly affect physical exertion perception or cognitive ability.

Keywords: Cold, Cognition, Perceived Exertion, Thermoregulation.

***Corresponding author:**
Scott M Graham
School of Applied Sciences, Edinburgh Napier University, Sighthill Court, EH11 4BN, Edinburgh, United Kingdom
Email:
S.Graham3[at]napier.ac.uk
Tel: 0131 445 6043

INTRODUCTION

The ability to be able to accurately determine workload and physical exertion enables athletes and coaches to minimise overexertion and injury [1] thereby reducing the risk of performance decrements [2].

Perceived exertion is acknowledged as a reliable and accurate indicator of exercise intensity and homeostatic disturbance [3] providing quantifiable measures of conscious sensations of strenuousness when performing a physical task [4, 5, 6]. During physical activity, the brain receives afferent sensory inputs from the muscles and joints [7], other parts of the central nervous system (CNS) [3] and cardiovascular (CV) and respiratory (RR) systems [5]. As muscle tension increases during physical activity the intensity of these signals is augmented [8].

The Borg scale [9] is the most widely used means to measure ratings of perceived exertion (RPE) [10] and is validated [11] utilising a numerical scale ranging from 6 "no exertion at all" to 20 "maximal exertion" [5]. RPE is influenced by physical fitness [12], experience [1], motivation, emotional state, temperature, gender and age [5] with reported values suggested to be lower in exposure to cold environments when compared to hot [13, 14]. However, some studies have reported no differences between cold and room temperatures [14, 15].

Exposure to cold temperatures elicits physiological reactions to maintain thermoregulatory homeostasis [16], vasoconstriction eliciting decreased heart rate (HR), increased stroke volume (SV) [18] and cardiac output (Q) [19] with concurrent reduction in blood flow to the working muscles [18] eliciting redistribution

of blood (shunting) back to the core [20].

Reduced blood flow to the muscles increases oxygen consumption (VO_2) [18] maintaining core temperature [20] with VO_2 positively correlated with RPE [5] and HR and RPE positively correlated [21]; a/lthough increased VO_2 has been hypothesised to affect accuracy of RPE [18]. The rate of substrate depletion, predominantly glycogen, is accelerated in the cold [22] due to increased demand from additional muscle fibres recruited to maintain workload [23]. Speed of muscle contraction is slower [24] due to decreased nerve conduction velocity [25] and resistance in the formation of cross-bridges [26], consequently, muscle force and power are diminished during cold exposure [25]. As glycogen availability diminishes the rate of adenosine triphosphate (ATP) regeneration decreases accelerating fatigue [27], consequently heat production is diminished, further decreasing core temperature [17]. Gender differences have been reported to affect thermoregulatory responses to cold temperatures [28].

Shivering increases metabolic heat production and offsets body heat lost to the cold [29] with males showing greater capacity to shiver more compared to females due to greater fat free mass [30]. Females rely more on insulation to preserve core temperature [30] as they have limited capacity for heat production [29] due to larger surface area, less muscle mass and a greater subcutaneous fat content compared to males [17], potentially having higher rates of heat loss compared to males [17]. Increased heat loss in females may affect the perception of exertion as lower muscle temperature decreases muscular performance [23], however, metabolic load from shivering increases oxygen consumption [31] potentially affecting males' RPE during cold exposure.

There are contradictory findings for gender comparisons in RPE at room temperatures. Parfitt, Markland & Holmes [33], reported higher RPE values in females than males for similar workloads, conversely Whaley [34] reported males had higher RPE values than females. However, Kim and Lee [35] reported no significant difference between male and female RPE data. In the only study, to date, investigating potential gender differences in RPE during cold exposure, Fournet *et al.,* [32] reported no gender related RPE differences.

Cognitive ability is crucial to respond to challenging situations and preserve personal safety [36] as cold environs elicit decrements in decision making [37] and reaction time [16, 38] which lead to increased injury risk. However, Taber *et al.* [39] reported no significant differences in cognitive ability after cold exposure, although participants in Taber *et al.* [39] were highly experienced in colder temperatures, which may have influenced the study's findings. It is not clear if individuals not habituated to cold environments are more vulnerable to cognitive deterioration.

Cognitive ability decrements potentially affect the ability to perceive exertion levels as cognition influences perceptual responses [40], with some chronic disease symptoms exacerbated in the cold [41]. Additionally, common symptoms of heavy exercise such as pain, dyspnea, and angina can be indicative of disease [5], therefore the risk of illness and, or, injury increases in cold temperatures more acutely when cognitive ability is diminished. The ability to distinguish between normal levels of exertion and unacceptable levels of physiological stress may be adversely affected due to impaired intrinsic ability to evaluate RPE.

A comprehensive understanding of the mechanisms and effects of exposure to cold environs on RPE has not been fully elucidated. The purpose of this study, therefore, was to investigate the effects of a cold environment on RPE during exercise compared to room temperatures and to establish if there are gender differences when measuring RPE in these conditions. Additionally, to determine if cognitive ability is impaired in cold temperatures and examine if significant differences in HR, skin temperature (T_{sk}), tympanic temperature (T_t),VO_2 and minute ventilation (V_e) occur between cold and room temperature environments. The study main hypotheses were that RPE would be higher in COLD conditions compared to the CONTROL; females would report higher RPE in COLD compared to CONTROL conditions; RT would be impaired in COLD compared to CONTROL conditions.

MATERIALS AND METHODS

Ethical approval was granted for this study by the SES Ethics Scrutiny, Edinburgh Napier University, Scotland. The study adhered to the Declaration of Helsinki. Sixteen recreationally active undergraduate students, male and female (m = 8, f = 8, age: 22.3 ± 1.7 years, stature: 177.5 ± 9.4 cm, body mass: 79.5 ± 17.0 kg (mean ± SD)) volunteered to participate in this study. Participants were recruited via social media and physical adverts and had relatively homogenous physical ability. Prior to testing participants were briefed on study protocols, completed a pre-test medical questionnaire and signed informed consent for participation. Participants were screened for exclusion criteria that may have potentially predisposed them to cold trauma.

This study followed a repeated measures design with randomly generated numbers determining allocation to a control or experimental condition. Participants attended the physiology laboratory on three occasions, for a familiarisation session, and to perform trial 1 or 2. Both trials were conducted in a temperature controlled environmental chamber (Weiss Gallenkamp, UK) in either the experimental condition (COLD; 5 degrees Celsius (°C)) or the control condition (CONTROL; 18°C, 55% relative humidity) dependant on randomisation allocation. Participants were required to abstain from alcohol, caffeine, and intense physical activity 24 hours prior to each visit and wore similar clothing (t-shirt, shorts and athletic shoes). Before and after each trial blood pressure was measured (Avant 2120, Nonin, USA). Trials were separated by 2 days and conducted at the same time of day to minimize circadian variation.

Stature (Freestanding stadiometer; Seca, Germany) and body mass (Scales; 808, Seca, Germany) were measured to the nearest 0.5 cm and 0.1 kg respectively. As participants were already familiar with the Astrand-Rhyming submaximal cycle ergometer test [42] a verbal explanation of the exercise protocol sufficed. The procedures for the Borg scale were detailed and explained [9]. Ten trials of the cognitive test were completed. Facemasks (V2, Hans Rudolph, Germany) were custom fitted to each participant.

Before entering the environmental chamber, participants completed a cognitive test (Simple detection; CogLab: The Online Cognition Lab, Cengage Learning) on a laptop (Thinkpad L540, Lenovo, United Kingdom). The test required participants to respond to a stimulus (green circle) which appeared at variable time intervals. Participants struck the response key (the letter "m") immediately after the stimulus appeared. Reaction time (RT) (milliseconds (ms)) was measured, with the mean across all 20 trials recorded. Immediately post-exercise participants re- took the test.

In the environmental chamber participants mounted a cycle ergometer (Velotron Pro, Racer Mate, USA), connected to a laptop (Satellite Pro L700-136, Toshiba, Japan). Following the collection of resting data (see 2.5) a 3-minute warm-up commenced at an inital workload of 50 Watts (W) for females and 75W for males. The workload increased by 25W to 75W for females and to 100W for males and was maintained for 6 minutes. Participants were instructed to maintain a self-selected pace. The exercise protocol was concluded with a 3-minute cool down set at 50W.

Prior to entering the environmental chamber, baseline resting measures of HR (RS400, Polar, Finland) RPE (12), T_t and T_{sk} were obtained. T_{sk} was assessed with thermistors (Grant, EUS-U-VS5-0,

Wessex Power, Dorset, UK), placed on the left side of the body at sites similar to that of Watkins *et al.* [37] and Taylor *et al*. [14]. Each thermistor was taped (Powertape, Andover Healthcare Inc, USA) and removed after each trial. The value of T_{sk} was obtained using data loggers (Squirrel 2020-1F8, Grant Instruments, United Kingdom). Mean T_{sk} of the four sites was calculated using the Ramanathan formula [43], where T represents temperature: $(0.3 \times [T_{chest} + T_{arm}]) + (0.2 \times [T_{upper\ leg} + T_{lower\ leg}])$. T_t was measured via the left ear using a thermometer (Type 6022, IRT 4520 ExacTemp, Braun, Germany).

After 2 minutes rest on entering the environmental chamber, baseline VO_2 and V_e were measured breath-by-breath (eight breath average), using an online gas analyser (Masterscreen CPX, Jaeger, Germany) connected to a facemask. During the exercise test T_t and T_{sk} were recorded at 2-minute intervals; HR, RPE, VO_2 and V_e were recorded every minute.

Statistical analysis was conducted using IBM SPSS Statistics Version 23 software package (IBM Corp., Armonk, NY, USA). Shapiro-Wilk tests were used to test for normality. A series of two-way (time x condition) repeated measures Analysis of Variances (ANOVA) (n = 6), were conducted to determine differences between environmental conditions over time on RT, T_{sk}, T_t, VO_2, V_e and HR. As all variables (excludingV_e and T_t) were non-parametric, data was log transformed. Where significant main effects were found, Bonferroni corrections were applied. In the case of significant interactions (time*condition), repeated and simple (first) contrasts were conducted. Data are reported as mean (*M*) ± standard deviation (*SD)*.

As RPE data was non-parametric, ordinal Friedman ANOVA tests were conducted between environmental conditions and gender. Any differences detected were subject to Bonferroni pairwise comparisons. Non-parametric descriptive statistics were reported as medians (*Mdn*) and inter-quartile ranges (*IQR*) (25^{th} – 75^{th} Percentile). Statistical significance was accepted at $p < 0.05$.

RESULTS

RPE scores significantly increased in both conditions through time ($\chi 2$ [15] = 175.077, p = 0.001) in both COLD and CONTROL after 2 minutes exercise until the conclusion of the test (p = 0.001) (Figure 1). However, there was no significant difference in RPE between conditions (p>0.05).

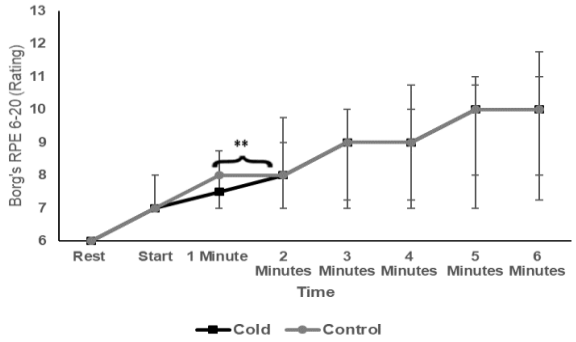

Figure 1: Median and interquartile ranges (IQR) of Borg's RPE 6-20 ratings across time in cold and control conditions (**p<0.05).

Female RPE ratings significantly increased across time ($\chi 2$ (15) = 101.104, p = 0.001) in both COLD and CONTROL (Figure 2). However, there was no difference between conditions (p > 0.05) (Figure 2). Similarly, male RPE scores significantly increased ($\chi 2$ (15) = 80.312, p = 0.001) across time in both conditions; with no difference in RPE between environments (p > 0.05). Gender comparisons showed no significant differences in RPE between males and females in COLD or in CONTROL (p > 0.05). Additionally, ANOVA tests showed that there were no overall differences in RT across time or between COLD and CONTROL conditions (p >0.05).

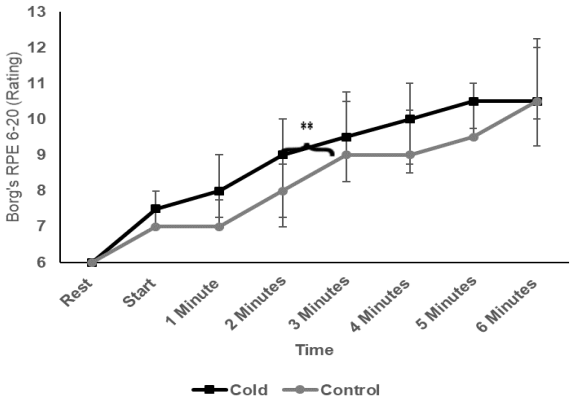

Figure 2: Median and IQR of females' RPE 6-20 ratings across time in cold and control conditions (**p<0.05).

There was a significant decrease (p < 0.05) in T_{sk} across time in both conditions. T_{sk} in COLD was significantly lower than CONTROL between rest and the start of exercise, and between 4 min and 6 min of exercise (p < 0.05). There were no other significant differences between CONTROL and COLD time points (p > 0.05) (Figure 3).

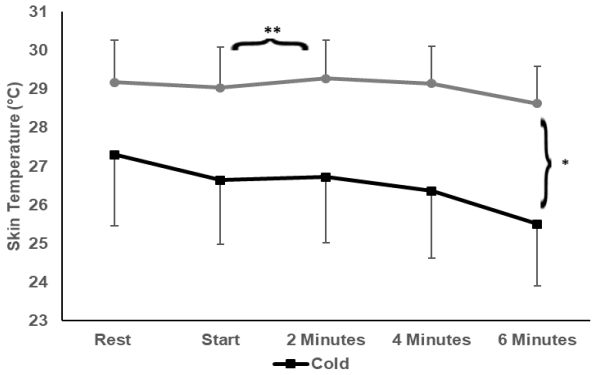

Figure 3: Mean ± standard deviation (SD) of skin temperature in cold and control conditions (**p<0.05).

T_t significantly decreased at all time points (p < 0.05) except between 2 & 4 minutes, 2 & 6 minutes and 4 & 6 minutes of exercise (p > 0.05) (Figure 4). T_t in COLD was significantly less than CONTROL at all time points except between rest & start of exercise and between 2 & 4 minutes of exercise (p > 0.05).

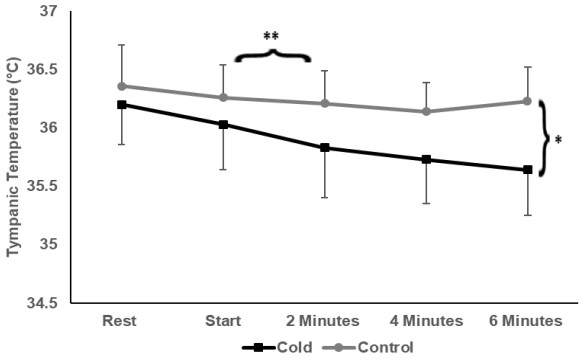

Figure 4: Mean ± SD of tympanic temperature across cold and control conditions (**p<0.05).

V_e significantly increased at all time points during the exercise (p < 0.05) except between 3 minutes and 6 minutes (p > 0.05). However, no significant interaction between time*condition was detected (p =0.883). VO_2 increased significantly (p < 0.05) from rest at all time

points, except between 3 mins and 6 mins of exercise ($p > 0.05$). HR significantly increased at all time points ($p < 0.05$) during the exposure in both conditions, except between minutes 5 and 6 of exercise ($p > 0.05$). There was no significant interaction between time*condition ($p > 0.05$).

DISCUSSION

This study's primary purpose was to determine if cold temperature influences RPE compared to room temperatures. The main findings showed no significant RPE differences between cold and control environments. A secondary aim was to determine if there are gender differences in the RPE response to cold and room temperature environs. Analysis showed no difference in the RPE between males and females in either environment. Furthermore, RT was not affected by time or environment. Therefore, the original study hypotheses were not met.

The main RPE results in this work are consistent with the findings of Nagelkirk *et al*. [15] and Taylor *et al*. [14]. RPE values were consistent in previous studies and in the present work (Figures 1) despite very different exercise protocols (90 min intermittent treadmill running [14], maximal cycle ergometer test [15] & short submaximal cycle ergometer test (present study)). Additionally, cold temperature was much lower in Taylor *et al*. (-5° C), compared to Nagelkirk *et al*. (5 – 8°C) and this study (5°C), however, it did not affect RPE. This suggests that mild to moderately cold temperatures do not adversely affect perceptual ability during exercise; however, more work is necessary to determine if RPE is influenced in more extreme acute temperatures or longer exposure to moderate cold.

Despite female RPE showing a trend to be higher than males (f = 10.5 (10 -12), m = 8 (7 – 10) (median ± IQR), this was not significant ($p > 0.05$). Additionally, there was no effect of gender on RPE between conditions. This supports the limited research comparing gender RPE data in cold and room temperature environs [32]. Similar to our findings, Kim and Lee [35] reported no gender differences in RPE at room temperature conditions, whereas in Parfitt *et al.* [33] females had higher RPE than males. In contrast, Whaley [34] found males had the higher RPE. These contradictory results may be due to differences in participants' experience and training status. Inactive participants tend to overestimate their RPE compared to their active counterparts [12]. Similarly, inexperienced participants tend to inaccurately interpret their RPE compared to experienced participants [1]. The participants in the present study were recreationally active and familiar with the exercise protocol, and so may have been more able to accurately interpret their RPE regardless of gender or short-term cold. Nevertheless, the tendency was for females to experience a higher RPE than males which may, in part, be attributed to females experiencing comparatively greater physiological strain compared to males [44]. The lack of statistical significance in these results may be due to inter-individual variability between participants; however, our main findings suggest gender does not appear to affect perception of exercise intensity in cold conditions.

Cold temperatures did not affect participants' RT in the present work and so did not diminish simple cognitive skills. Mäkinen and colleagues [36] reported that RT was adversely affected for simple skills in their study examining the effects of cold non-hypothermic conditions on cognitive ability. Others [16, 38] have also reported RT to be significantly slower in cold temperatures. The battery of tasks in Mäkinen *et al*. [36] highlights the complexity of cognition, in that some tasks are impaired, whilst others are improved in a cold environment. Of note, is that in the previous studies [36, 16, 38] participants were tested in resting cold conditions, whereas, in the present study participants performed RT tasks immediately after sub-max exercise in the cold. Physiological responses to exercise in the cold differ from that of resting [28] and so may subsequently affect RT. Moreover, the time spent in the cold was much shorter in this work (~15 min) compared to Mäkinen *et al.* [36] (100 min) and Muller *et al*. [16] (120 min). Additionally, in the present study, and in Mäkinen *et al*. [36], simple reaction time tasks (SRTT) were used, however Muller *et al*. [16] and Rammsayer *et al*. [38] used choice reaction time tasks (CRTT). RT during CRTT is more variable than SRTT [50], and so may further account for differing outcomes.

There was a significant overall decrease in T_{sk} (Figure 3) and T_t (Figure 4) in the cold compared to the control in this study. However, there was no concurrent difference between environmental conditions in the physiological variables V_E, VO_2, or HR. The decline observed in T_{sk} can be attributed to vasoconstriction and reduced heat transfer from the core to the skin [20]. A potential mechanism responsible for the decrease in T_t is a reduction in the thermal gradient between the skin and environment [45]. Kim *et al*. [45] also reports a drop in T_t as a result of 60 min sub-max cycling (65% VO_{2max}) in the cold (5 ± 1°C), however, others [46, 47] have found no difference. In Lintu *et al.* [47], measurements were taken before and after 30 mins cold exposure (-5° C) and therefore, may not fully represent time dependent T_t response in the cold. Similarly, T_t was measured before and after 15 min exposure to cold (-5° C) in Doyle *et al* [46]. In Lintu *et al*. [47] and Doyle *et al.* [46] exposure to cold was passive, however, in the present work, and in Kim *et al.* [45], sub-max cycling exercise was performed. It is not clear if exercise may have influenced the thermal gradient between skin and environment affecting T_t.

There were no other significant differences in physiological measures between cold and control environments in this study. Whilst other work has also found no difference in V_E between environmental conditions [48], some have reported that V_E was significantly higher in the cold [22]. Longer exposure time in these studies [22] could account for the differences in findings. As cold increases V_E [18], longer exposure increases respiratory muscles fatigue causing further increases in V_E [49]. Similar to the present study, Nagelkirk *et al.* [15] and Sommerville *et al.* [48] found no environmental effect on VO_2. However, Haman *et al*. [22] did find VO_2 to be significantly higher in the cold. This may be because in Haman *et al*. [22] participants left the environmental chamber to have VO_2 measured, potentially increasing the metabolic load compared to the control group who remained stationary. HR in this work was not significantly different between cold and control environments, supported by Galloway and Maughan [16] and Nagelkirk *et al.* [15]. However, in Kim *et al*. [45] HR was lower in the cold condition (5° C). The longer duration of sub-maximal exercise (60 min), compared to the present study (12 min; 3 min warm up, 6 min test, 3 min cool down) may be responsible for this disparity.

CONCLUSION

This study found that short duration submaximal cycling exercise in cold conditions did not affect perception of exercise intensity or RT in simple cognitive skills compared to room temperatures. Additionally, RPE was not affected by gender. This suggests that there is no increased risk of performance decrement or injury risk due to impairment of judgment in healthy young persons under similar conditions. Despite a significant drop in T_{sk} and T_t, there were no environmental effects on VO_2, V_E or HR. This may have further influenced the RPE findings between conditions. However, an absence of effect on RPE due to cold supports similar findings by others. Future studies should examine the effect of cold in more extreme exercise and environmental conditions, and in more challenging cognitive scenarios to deepen understanding of potential performance impairment.

A comprehensive understanding of the mechanisms and effects of exposure to cold environs on RPE has not been fully elucidated. This study found that cold conditions did not affect perception of exercise intensity during short duration submaximal cycling; gender differences were not found. Reaction time in simple cognitive skills was no different compared to room temperatures. Suggesting no increased risk of performance decrement or injury risk due to impairment of judgement.

Conflicts of Interest

The authors have no conflicts of interest to declare.

Authors' Contribution

Gandy A. Concept and design of study, acquisition of data, analysis and interpretation of data, drafting and revising the manuscript for important intellectual content, final approval of version to be published.

Baird MF. Analysis and interpretation of data, revising the manuscript for important intellectual content, final approval of version to be published.

Boyd GW. Analysis and interpretation of data, revising the manuscript for important intellectual content, final approval of version to be published.

Connaboy C. Analysis and interpretation of data, revising the manuscript for important intellectual content, final approval of version to be published.

Graham SM. Concept and design of study, analysis and interpretation of data, drafting and revising the manuscript for important intellectual content, final approval of version to be published.

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