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Heart Rate Variability Response in Children Working at Height

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ABSTRACT

Working at height is a hazardous condition for children. Their lack of maturity in making decisions, in various situations, creates anxiety and stress. Stress from fear of falling from height requires special attention when working. A simulation of light workload tasks at 1 to 10-meters height was conducted in boys with (n=30) and without (n=30) experience. Psychophysiological responses were investigated with heart rate variability (HRV) measurement. The result showed that the time domain of the HRV between groups indicated similar responses in the autonomic nervous system (ANS) at each height. However, ANS activities increased along height levels. The mental stress as a result of the working at height affected sympathetic predominate and lower parasympathetic activity. Conversely, the experience of the working at height influenced heart rate control.

Keywords: Heart rate variability (HRV); Children; Work at height

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1. Introduction

Working at height is one hazardous work condition requiring climbing and walking up and down, possibly in a narrow working space. Children may have been assigned to work at height as well as smaller workers. Falls from height could lead to physical trauma, permanent disability, and a high rate of fatalities [1]. Several countries are concerned with this hazardous condition especially when involving workers [2].

Children have been defined differently in age range when dealing with working. In addition, legislation laws in relation to working at height in children are diverse across countries. There are the protections of the youth 14 to 17 years in the United States. However, youth under the age of 18 are not allowed to be employed under the US workforce and hazardous occupations [3]. There are regulations for employing children under 14 or 15 years old in Australia, which differ in each state depending on types of employment and state law [4]. The Thai Labour Protection Act B.E. 2541, in Section 44, states that employers shall not employ a child under 15 years of age as an employee [5], the same as in Vietnam and the Republic of South Africa [6-8]. In addition, Section 49 of the Thai Labour Protection Act B.E. 2541 indicates that employers shall not assign a young worker under 18 years of age to work on scaffolding higher than 10 meters above the ground [5]. In the current study, children refer to those aged 15 to under 18 years.

Available safety guidelines are mostly for adult workers [2, 9-11]. Nevertheless, the rationale for such guidelines has not been provided and no specific regulations or guidelines exist for children working at height. This could be hazardous work because in some countries, this is prohibited for children. However, some countries still allow children to work at height in a specified working height level up to 10 meters [5]. As working at height is a hazardous work environment for adult workers, this is even greater for children. Incidence rate of falling from height has been reported as a result of accidents. In Turkey, the accidents were reported from 1-8 storeys. Among 484 accident cases, 224 cases fell from 1-5 meters [12]. According to the accident injuries, children aged under 15 years fell from 4-meter height, and children aged over 15 years fell from 9-meter height [13]. Based on the Annual Report 2017 of Workmen's compensation fund, Social Security Office, for workplace accidents in Thailand, falling from height was reported in 5,553 cases including 101 cases of death, 6 cases with disability, and 28 cases with damaged organs [14]. Impact of injury from high falls depends on fall height. Mortality increased in relation to working height level [2, 14]. Falling from 1-meter height could lead to injury or death [1, 12, 14]. The risk of working at height in children is likely to be greater than in adult workers and requires more attention to ensure that they are properly protected due to their lack of maturity and experience, being unaware of existing risks [15]. Lack of maturity in working at height may cause danger from absence of caution and carefulness, lack of decisions and solving problems in various situations. The impetuousness of youth may also result in the risk of accidents causing injuries or deaths, falling from a height. Work safety is therefore important in providing protection in the occupational safety, health and working environment for children as well as adult workers. The laws on children working needed to be enforced for prevention of accidents.

Apart from accidents, it is still unclear about psychophysiological responses while working at height. Steady state is paramount for any urgent situation that challenges to life. Postural stability and reaction time have been explored while a person is standing at a high place [10, 16, 17]. Increasing of the floor level height resulted in increased heart rate and reduced postural stability as reported in construction workers [18].

Cardiovascular response is controlled by the central nervous system through the autonomic nervous system (ANS). ANS is divided into sympathetic and parasympathetic systems. Cardiac autonomic function can be assessed by analyzing heart rate variability (HRV) [19-23]. During working at height, the operators must pay special attention to prevent hazards such as falling from height, injury, or death [2, 9]. The mechanism underlying the cardiovascular function is associated with an altitude exposure by increasing the frequency of the heartbeat. The cardiovascular response to altitude has been investigated by measuring intervals between consecutive heartbeats (R-R intervals). The result showed that the mean R–R interval is decreased [24, 25].

Studies regarding psychophysiological responses to work at height in children have not been reported. HRV as stress measurement in children revealed association between low frequency/ high frequency ratio (LF / HF ratio) and anxiety. Low HRV (lower parasympathetic activity) may be suitable to determine stress level in children [22]. To better understand psychophysiological phenomena, the study of the cardiovascular responses to stress in children working at height requires attention. This could be used to establish a guideline for preventing the hazardous risk of working at height for children. Therefore, the objectives of the current study were to explore psychophysiological responses using HRV while working at height of 1 to 10 meters in boys with and without experience working at height in comparison to the ground level.

2. Method

2.1 Participants

Thai boys aged between 15 to under 18 years participated in the study. A total of 60 boys were divided into two groups, with work at height experience (n=30), and without work at height experience (n=30). The boys with the experience were recruited from a military technical training school. They have been trained and practiced in operating on electricity towers at 10 - 15 meters height for at least 6 months. The boys in the non-experience group were recruited from secondary schools in Bangkok. Participants with abnormalities in the nervous system, musculoskeletal system, cardiovascular system, and/or acrophobia, an urge to jump off high place phenomenon [26] were excluded from the study as well as those with a below average physical performance.

Ethical approval was obtained from the Ethical Review Sub-Committee Board for Human Research Involving Sciences, Thammasat University (ECScTU), No.3. Participants voluntarily provided the written consent and their parents or legal guardian provided written informed consent for their children.

2.2 Experimental design

An experimental study with repeated measures was implemented in this study. The study was conducted in a safe indoor environment with light workload. All participants wore the body harness under permanent infrastructure and railing for safety and fall protection. The psychophysiological response variables consisted of heart rate (HR), heart rate variability (HRV) in time domain, low-frequency normalized units (LF n.u.), high-frequency normalized units (HF n.u.), and low frequency/ high frequency ratio (LF / HF ratio). All variables were recorded at ground level and at each height level from 1 to 10 meters, consecutively.

2.3 Procedure

The participants were invited to sit in a quiet area, where they were unable to see a workstation. An instruction of work at height simulation was informed to the participants. In standing, they were asked to tie cables around handrails for 7 minutes as light tasks, which were exposed to the working height at 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 meters from the ground.

The participants were asked to wear HR recorder (Polar V800, Polar Electro Inc, Finland) on their chests. After a 5-minute rest period, the HRs were recorded for 1-minute while sitting to represent resting HR.

The participants were then suited with fall protections, body harnesses, and safety helmets by work at height professionals. After a few minutes of resting in sitting, the HRs at ground level (HR at rest) were recorded for 7 minutes. The participants were asked to step up to the workstation at 1-meter height. They were asked to sit there until HRs were not greater than their own HRs at rest. The participants were then allowed to perform the light task while standing for 7 minutes. They were asked to complete the task at all levels with the increment one-meter height in order. During the tasks, the HRs were recorded at each height. The same step of sitting at the next higher level until HRs were within participant's HR at rest and performing the light task afterward for 7 minutes were implemented at each level. HRs were used to analyse for a short-term of HRV [19, 20, 27]. HR and HRV at ground level in sitting were used as baseline value for the comparison with working at height which involved fight or flight responses [28].

2.4 Data analysis

The HRV data during working at all levels were analyzed with the Kubios HRV software. The Kolmogorov Smirnov Goodness of Fit Test was used to determine the distribution of data. The independent t-test and Mann-Whitney U test were used to analyze the differences between the groups. The Friedman test for non-normal distributed data was used to analyze data of all the height levels within each group.

Table 1. Characteristics of participants.

	Boys with work at height experience (n=30)		Boys without work at height experience (n=30)		*p*-value
	Mean ± SD	Median	Mean ± SD	Median	
Age (years)	16.90 ± 0.31	17.00	16.03 ± 0.72	16.00	< 0.001[*b]
Weight (kg)	62.13 ± 5.96	60.40	63.26 ± 10.24	60.00	0.604[a]
Height (cm)	170.53 ± 4.68	170.00	171.70 ± 5.56	170.00	0.383[a]
BMI (kg/m^2)	21.36 ± 1.81	21.11	21.41 ± 3.01	20.98	0.631[b]
Leg strength per body weight (%)	2.21 ± 0.46	2.22	1.85 ± 0.55	1.78	0.008[*a]
Resting heart rate (bpm)	71.43 ± 6.88	72.00	73.60 ± 7.36	72.00	0.529[a]

* Significances were defined as p-value < 0.05, [a] with Independent t-test and [b] Mann-Whitney U test.

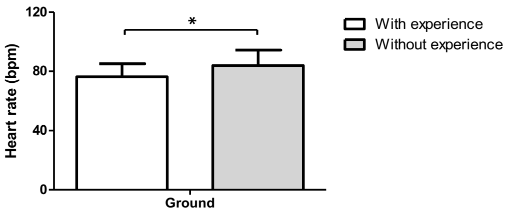
3. Results

Descriptive characteristics of the participants are presented in Table 1. Age and the leg strength per body weight were significantly different between groups (p <0.05).

3.1 Heart rate index

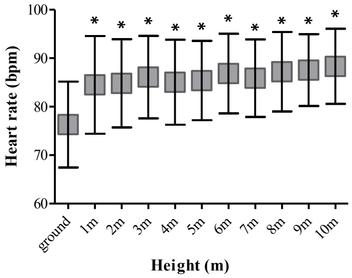
There was a statistically significant difference of HR at the ground level between the groups with work at height experience (76.33 ± 8.86) and no experience (83.90 ± 10.48), (p < 0.05, d = 0.78) (Fig. 1) and other levels (84.50 ± 10.08 to 88.33 ± 7.75, 91.20 ± 11.28 to 97.06 ± 12.09 in the group with and without experience, respectively, p < 0.05, d = 0.63-0.96).

Within each group, there were statistically significant differences of HR between at the ground level compared to the other levels (p < 0.05) in the experience (Fig. 2) and no experience (Fig. 3) groups.



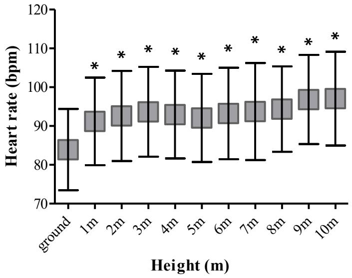
* Significance was defined as p-value < 0.05 with Independent t-test.

Fig. 1. Comparison of HR at ground level between groups.



* Significances were defined as *p*-value < 0.05 with Friedman test.

Fig. 2. HR at ground level compared to other levels in boys with experience.

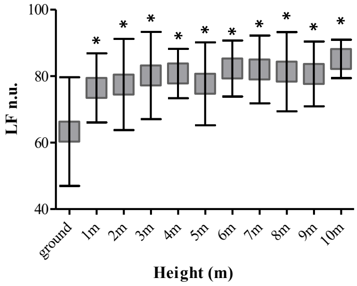


* Significances were defined as *p*-value < 0.05 with Friedman test.

Fig. 3. HR at ground level compared to other levels in boys without experience.

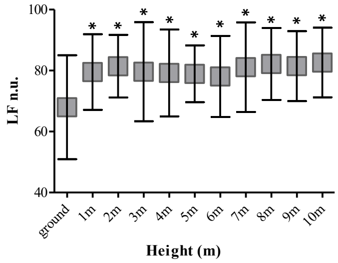
3.2 LF n.u.

There were statistically significant differences in the LF n.u. at all levels as compared with the ground level in each group ($p < 0.05$) as shown in Figs. 4 and 5. At the level of 1-10 meters, the mean LF n.u. of the boys with experience ranged between 63.33 ± 16.34 to 85.18 ± 5.77. The LF n.u. of the boys without experience ranged between 67.99 ± 17.04 to 82.64 ± 11.42. There was no significant difference between groups.



* Significance was defined as *p*-value < 0.05 with Independent t-test.

Fig. 4. LF n.u. at ground level compared to other levels in boys with experience.

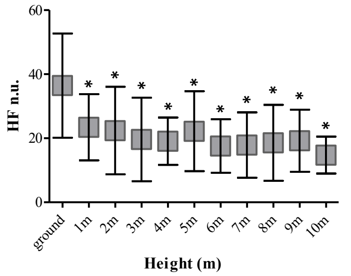


* Significance was defined as *p*-value < 0.05 with Independent t-test.

Fig. 5. LF n.u. at ground level compared to other levels in boys without experience.

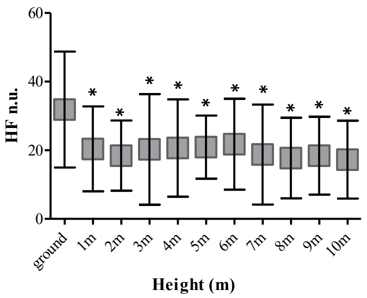
3.3 HF n.u.

There were statistically significant differences in the HF n.u. between at the ground level compared to the other levels in each group ($p < 0.05$) as shown in Figs. 6 and 7. At the level of 1-10 meters, the mean HF n.u. of the boys with experience ranged between 14.75 ± 5.77 to 36.46 ± 16.27. The HF n.u. of the boys without experience ranged between 17.27 ± 11.36 to 31.85 ± 16.90. There was no significant difference between groups.



* Significance was defined as *p*-value < 0.05 with Independent t-test.

Fig. 6. HF n.u. at ground level compared to other levels in boys with experience.



* Significance was defined as *p*-value < 0.05 with Independent t-test.

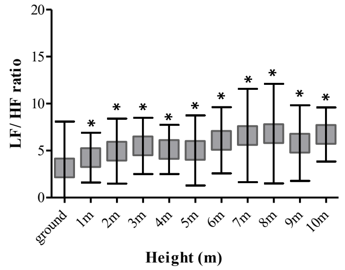
Fig. 7. HF n.u. at ground level compared to other levels in boys without experience.

3.4 LF / HF ratio

There were statistically significant differences in the LF / HF ratio between at the ground level compared to the other levels in each group ($p < 0.05$) as shown in Figs. 8 and 9. At the level of 1-10 meters, the mean LF / HF ratio of the boys with experience ranged between 3.17 ± 4.93 to 6.82 ± 5.30. The LF/ HF ratio of the boys without experience ranged between 3.45 ± 3.66 to 7.56 ± 5.77. There was no significant difference between groups.

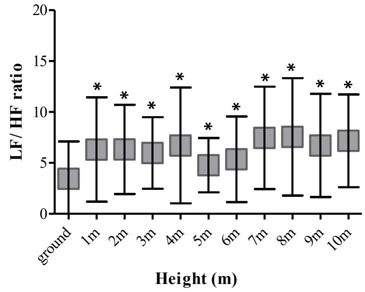
4. Discussion

This study explored psychophysiological responses of boys working at various height levels and compared these responses in boys with and without work at height experiences.



* Significances were defined as *p*-value < 0.05 with Friedman test.

Fig. 8. LF/HF ratio at ground level compared to other levels in boys with experience.



* Significances were defined as *p*-value < 0.05 with Friedman test.

Fig. 9. LF/HF ratio at ground level compared to other levels in boys without experience.

4.1 Psychophysiological responses of working at height in boys

While working at a height of 1 - 10 meters, HR increased as a response mechanism when exposing altitude [20, 23-25]. Previous research in altitude exposure showed association with major changes in cardiovascular function. The initial cardiovascular response to altitude is characterized by an increase in cardiac output with tachycardia with no change in stroke volume [11]. Another possible mechanism to increase HR may be due to physical activity. Body movement could induce HR increase due to the increase in sympathetic modulation and withdrawal of parasympathetic activity [20].

Our results showed that when working at height, HR increased in comparison to ground level in both groups. Similar responses were found in previous research that mental stress increased in high-voltage transmission tower construction workers working at high surfaces [11]. Working at 1-10 meters, HR of boys with work at height experience was in normal range [29] while no-experience group showed increased HR (HR > 90 bpm).

LF n.u., HF n.u. and LF/HF ratio were used to evaluate ANS function in young children at different height levels from 1 to 10 meters and ground level in this study. LF n.u. indicates the functions of both sympathetic and parasympathetic outflow [20, 21] while HF n.u. reflects the parasympathetic activity [19, 20]. The representation of LF and HF in n.u. may emphasize the controlled and balanced behavior of the two divisions of the ANS but not HR behavior [19]. In addition, LF/HF ratio represents sympathetic predominate [19] as well as mental stress [11, 22]. Working at heights of 1 to 10 meters, LF n.u. and LF/HF ratio increased as level of working height increased. These results suggest that adjustment of ANS was due to the increase in sympathetic and parasympathetic outflow in height levels as compared with the ground level. The increase of LF/HF ratio in working at height as compared with the ground level indicated the dominance of sympathetic function and greater mental stress. This was in contrast to previous findings of working at height in adult workers which found that LF n.u. and LF/HF ratio reduced and the HF n.u. increase [11]. This difference could be explained by working at height level greater than 15 meters affecting LF band [11]. The sources of the ecological stressor associated with the working height included the sense of insecurity and uncertainty [11]. For the tower construction work, the workers must have vigilance during working. They had to monitor and continually observe various factors and correct action immediately for unexpected situations. Making a single mistake can result in serious injury or death. The working environment is another possible stressful factor such as thermal sensations, working off balance or dealing with the fear of falling or flying objects, and strong wind. All of these factors could cause higher mental stress/higher mental demand and be associated with an increase of LF power and a decrease of HF power as well as an increase of the LF/HF ratio [9]. In contrast to previous studies, adjustment of ANS in this study showed a different mechanism. This may be due to the simulation of work at height environment that could be less stressful both physically and mentally. Moreover, all participants performed light work at the height level lesser or equal to 10 meters, in safe environment with room temperature controlled, and needed not to consider about stressful situation.

4.2 Comparison between boys with and without experience working at height

LF n.u., HF n.u. and LF/HF ratio of boys with or without work at height experience were not significantly different at all height levels. This suggested that ANS plays a similar role in both groups. However, HR control was more prominent in boys with work at height experience given the increase of HRs while working at higher levels was found in the non-experienced group rather than in the experienced group. This finding is similar to the study of working at height in construction workers [18].

There were some limitations in this study. As this is the first study conducting the experiment of working at height in children and with the concern of ethical issue, work at height station was set in indoor environment with the safety protection. Exposing to the real environment would have to be carefully explored in future study to ensure safety for children working at height and whether or not this kind of work should still be allowed based on psychophysiological study.

5. Conclusion

The results of HRV in the frequency domain while working at height were similar between boys with and without work at height experience in each height level. ANS activity increased when working at higher surface levels. Conversely, HR response implied that experience in working at height affected HR control.

Acknowledgements

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