Thirst as the threshold symptom to prevent worsening heat-related illness

Zawiah Mansor, MPH[1], Noor Hassim Ismail, MSc(Occupational Health)[1], Rosnah Ismail, DrPH[1], Jamal Hisham Hashim, PhD[2]

[1]Department of Community Health, Faculty of Medicine, Universiti Kebangsaan Malaysia Medical Center, Cheras, Kuala Lumpur, Malaysia, [2]United Nations University-International Institute for Global Health (UNU-IIGH), Universiti Kebangsaan Malaysia Medical Center, Cheras, Kuala Lumpur, Malaysia

ABSTRACT

Introduction: The heat-related illness (HRI) is a continuum illness ranging from minor health effects to life-threatening medical emergencies when the pathological effects of heat load are not prevented. The aim of this study was to demonstrate the threshold HRI symptom for deciding to take simple preventative actions both by the individual workers and employers.

Method: A total of 328 municipal workers were enrolled in April to March 2016 were asked to recall if they experienced eleven HRI symptoms during the previous work day. Rasch Measurement Model was used to examine the unidimensional parameters and bias for gender before identifying the threshold of HRI symptoms. We determined the threshold symptom based on the person-item map distribution on a logit ruler value.

Results: A total of 320 respondents were analysed. The psychometric features HRI symptoms suggested evidence of unidimensionality and free of bias for gender (DIF size =0.57; DIF t value =1.03). Based on the person-item map distribution, the thirst item was determined as the threshold item (Cut-off point = -2.17 logit) for the preventative action purposes to group the person as mild and moderate/severe HRI groups.

Conclusion: Thirst item is viewed as threshold symptoms between mild and moderate or severe HRI symptoms. It is a reliable symptom to initiate behavioural response to quench the thirst by adequate fluids. Failure to recognise the thirst symptom may lead to devastating unwanted health complications.

KEY WORDS:
Heat-related illness, Rasch Measurement Model, thirst symptom

INTRODUCTION

Heat-related illness is defined as a physiological insult to the body from exposure to heat overload, which can lead to elevation of core body temperature that surpasses the compensatory limits of thermoregulation.[1] It encompasses disorders ranging from minor health effects i.e., from fatigue and heat rashes to life-threatening medical emergencies i.e., heat cramps, heat syncope, heat exhaustion and heat stroke. Workers at risk for HRI include outdoor and indoor workers in hot environments such as fire-fighters, bakery workers, farmers, construction workers, miners, boiler room workers and factory workers.[2]

Although anyone can suffer from heat overload regardless of age, sex, or health status,[3] the pathological effects of heat load are preventable. The exposure to the heat load among construction workers can be managed through control of environmental heat load by use of an action-triggering threshold system, control of continuous work time with mandatory work-rest regimens, and enabling self-paced working through empowerment of employees.[4] Others suggest control measures through administrative adjustments such as rescheduling of work rotation, providing drinking water, monitoring human heat strain, and personal engineering controls such as using cooling vest.[5] However, these measures are considered ineffective if the workers themselves cannot appreciate the importance of the existence of vital HRI symptoms. These symptoms can be a powerful self-centred 'action-triggering' the workers to adopt the existing control measures to reduce the effects of heat load.

The common symptoms of HRI are feeling of tiredness, cramps, nausea, dizziness, thirst, vomiting, confusion, muscle weakness, heat sensations on the head or neck, chills, and feeling of lightheadedness.[6] These symptoms are the consequences of heat overload exposure resulting in activation of collective autonomic heat-defence activation effectors affects the regulation of homeostatic systems other than thermoregulation mechanisms, such as cutaneous vasodilation, evaporation and cold seeking behaviour.[7] Increased cutaneous vasodilation and decreased venous tone reduces ventricular filling leading to low brain perfusion and heat syncope while standing. Electrolyte imbalance can develop due to excessive sweating, and promote the occurrence of heat cramps, i.e., short-lived, painful contractions of skeletal muscles during or after prolonged work in the heat. In severe hypovolemia, heat exhaustion develops with domination of water or salt-depletion. The former is mainly due to insufficient fluid replacement which initiates the feeling of thirst, worsening of hypovolemia, progressive hyperosmolarity and hyperthermia. Salt-depletion dominates when sweating-induced water loss is replaced by water. But deficiency in salt content leads to hypoosmolarity in hyponatremia and its consequences.[7] The

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Corresponding Author: Dr Rosnah Ismail
Email: drrose@ppukm.ukm.edu.my

condition may result in water movement into the brain cells in response to the osmotic gradient, selectively glial cells with sparing of neurons thus causing cerebral edema.[8] Further, uncompensatory hypovolemia under heat overload exposure leading to circulatory shock and progressive hyperthermia due to failure of thermoregulatory mechanism may result in heat stroke. In view of these physiological changes, feeling of thirst is easily recognised by workers. It indicates that blood volume changes have begun. We hypothesize feeling thirsty as an important threshold symptom that predicts flight of HRI severity from mild to moderate or severe illnesses.

Rasch Measurement Model (RMM) was used to prove this hypothesis because its uniqueness to demonstrate the intangible measurement through person-item map in the form of two vertical histograms. The map displays relations between the hierarchical items of HRI symptoms and personal experience of each HRI symptom distributed at side by side which measured by single logit ruler. We expect a reverse relationship between persons with symptoms of HRI and frequency of HRI symptoms endorsement during the previous work day. Persons with least symptoms of HRI should have a higher probability of reporting lower hierarchy of HRI symptoms, and those with most symptoms of HRI should experience a lower probability of reporting higher hierarchy of HRI symptoms.

METHODOLOGY

Study Design and Population

This study was conducted in eight different zones in a district in Negeri Sembilan from 29 March to 8 April 2016. The study was done at the end of the El Nino phenomena in Malaysia when the average ambient temperature was 32.84°C (28.05 to 38.76°C). Based on the sample size calculation for known population,9 a total of 340 out of the 2000 outdoor workers from a municipality company involved in cleaning streets, drains, and cutting the grass at the roadside were selected. They were selected by random from the given name list of workers the municipal company. The inclusion criteria were: Malaysian, age 18-year and above, had worked for at least six months in the company and 8-hour shift per day. Workers who were not proficient in Malay or English language or had been on leave for more than two days in previous two weeks before the start of the study were excluded.

Instruments

The questionnaires were used for the data collection were in Malay and includes socio-demographics variables (e.g., age, gender, race, education, job title and service duration) and HRI symptoms. A previously validated questionnaires about eleven HRI symptoms were used.[6] It was distributed at the end of the work day. The respondents were asked to recall if they experienced symptoms of HRI during work for that day: feeling tiredness, cramps, nausea, dizziness, thirst, vomiting, confusion, muscle weakness, heat sensations on the head or neck, chills, and feeling lightheaded. For each symptom, respondents were asked to rate the severity of the symptom on a graduated scale after the corresponding work session. A five-point Likert of severity ratings ranging from 1 to 5 and including the following anchors: 1=no symptoms, 2=mild symptoms that did not interfere with practice, 3=moderate symptoms, 4=severe symptoms requiring a break from practice and 5=very severe symptoms that caused them to stop practice. Briefing was given to all respondent prior to the questionnaire distribution in which, HRI symptoms were assessed regardless of adaptation measures taken by the respondent (e.g., drinking water or going to cooler areas). In our study, Cronbach's alpha of eleven HRI symptoms was 0.83.

Rasch Measurement Model Analysis

A total of 320 cleaned data of HRI symptoms in IBM SPSS version 23 were converted into Winsteps construct file that was fitted to the Rasch model using Winsteps software version 3.72.3. The list of HRI symptoms was further examined for unidimensional parameters, i.e., point measure correlation and four fit statistic of items, Principal Component Analysis (PCA) of the residuals and Differential Item Functioning (DIF), as follows, before analysing person-item map:

1) The point-measure correlation is a summary of a relationship between both discrete variables with more than two equally spaced values of a Likert-scale survey.[10] An item was deemed as fitting the Rasch measurement model if the point measure correlation was between 0.4 and 0.85 and four fit statistics indices were fulfilled. The infit statistic indices are more sensitive to irregular on-target response patterns and expressed in two forms: infit mean square (MNSQ) and Z distribution. The outfit statistic indices are more sensitive to irregular off-target response patterns and expressed in two forms: outfit mean square (MNSQ) and Z distribution. The mean square should range between 0.6 and 1.4, and the Z-standard is between -2 and +2.[11]
2) The PCA of the residuals was run to demonstrate the unidimensionality of the HRI symptoms. Unidimensionality was considered fulfilled if a) raw variance explained by the measure more than 40%, b) ratio raw variance explained by items/unexplained variance in 1st contrast is five and above, c) the unexplained variance in first contrast was less than three Eigenvalue and d) the standardised residuals contrast 1 plot demonstrate randomness.
3) The HRI symptoms were tested for the presence of DIF i.e., gender bias. Gender bias, if present, DIF size of more than 0.50 logit with t-value >2. DIF size is the difference between the DIF measure and the baseline measure for gender. Gender was coded as "M" for male and "F" for female.

Lastly, the person and item map was displayed to examine a logit ruler created from the measurements of respondents' rating of their own experience on the different degree of severity level to order HRI symptoms in a hierarchical direction. This will be the premise of the instrument to identify the threshold HRI symptoms which further classify mild to moderate or severe groups of HRI symptoms.

RESULTS

A total of 328 out of 340 questionnaires were returned, giving response rate of 96.4%. Initial analysis showed that eight respondents had not answered any of the HRI symptoms. Therefore, they were excluded from the analysis to enhance

Table I: Point Measure Correlation and Four Fit Statistic of HRI Symptoms

Entry	Measure	MODEL S.E.	INFIT		OUTFIT		Point Measure		SYMPTOMS
			MNSQ	ZSTD	MNSQ	ZSTD	CORR	EXP	
6	2.18	0.20	1.38	1.40	0.90	0.00	0.40	0.41	Vomiting
7	1.76	0.16	1.96	3.40	0.89	-0.10	0.40	0.46	Confusion
10	1.64	0.15	1.31	1.40	1.00	0.10	0.46	0.47	Chills
3	1.10	0.12	1.39	2.10	1.23	0.80	0.49	0.54	Nausea
11	0.81	0.10	1.71	4.00	1.03	0.20	0.51	0.57	Lightheaded
2	-0.38	0.07	1.08	0.90	0.91	-0.50	0.70	0.70	Cramps
8	-0.60	0.07	0.94	-0.70	0.74	-1.90	0.75	0.72	Muscle weakness
4	0.95	0.07	1.21	2.30	1.33	2.30	0.68	0.73	Dizziness
9	-1.07	0.06	0.72	-3.60	0.62	-0.35	0.81	0.73	Heat sense
5	-2.17	0.06	0.77	-3.10	0.88	-1.10	0.69	0.67	Thirsty
1	-2.32	0.06	0.70	-4.10	0.85	-1.50	0.63	0.65	Feeling tired
Mean	0.00	0.10	1.20	0.30	0.94	-0.50			
S.D.	1.51	0.05	0.39	2.70	0.19	1.40			

Table II: Standardised Residual variance (in Eigenvalue units)

		Observed			Expected
Total raw variance in observations	=	37.7	100.0%		100.0%
Raw variance explained by measures	=	26.7	70.8%		70.9%
Raw variance explained by persons	=	7.7	20.3%		20.4%
Raw Variance explained by items	=	19.0	50.5%		50.6%
Raw unexplained variance (total)	=	11.0	29.2%	100.0%	43.8%
Unexplained variance in 1st contrast	=	1.6	4.3%	14.6%	
Unexplained variance in 2nd contrast	=	1.3	3.5%	12.0%	
Unexplained variance in 3rd contrast	=	1.3	3.5%	11.8%	
Unexplained variance in 4th contrast	=	1.3	3.4%	11.7%	
Unexplained variance in 5th contrast	=	1.1	2.9%	9.8%	

Table III DIF Report: Gender class within item

Gender	Observation		Baseline		DIF	DIF	DIF	S.E.	t-value	Item	HRI
Class	Count	Average	Expect	Measure	Score	Measure	Size			Number	Symptoms
M	148	2.38	2.40	-2.32	-0.02	-2.29	0.03	0.10	0.28	1	Lethargy
F	172	2.22	2.20	-2.32	0.02	-2.34	-0.02	0.09	-0.25	1	Lethargy
M	148	0.95	0.87	-0.38	0.08	-0.49	-0.11	0.10	-1.13	2	Cramps
F	172	0.77	0.83	-0.38	-0.06	-0.26	0.12	0.11	1.13	2	Cramps
M	148	0.13	0.19	1.10	-0.06	1.43	0.33	0.21	1.60	3	Nausea
F	172	0.31	0.26	1.10	0.05	0.88	-0.22	0.15	-1.50	3	Nausea
M	148	1.11	1.31	-0.95	-0.20	-0.70	0.25	0.09	2.72	4	Dizziness
F	172	1.35	1.17	-0.95	0.18	-1.22	-0.27	0.09	-2.94	4	Dizziness
M	148	2.36	2.29	-2.17	0.06	-2.26	-0.09	0.10	-0.93	5	Thirst
F	172	2.03	2.08	-2.17	-0.05	-2.11	0.07	0.08	0.79	5	Thirst
M	148	0.03	0.05	2.18	-0.03	2.75	0.57	0.42	1.34	6	Vomiting
F	172	0.12	0.10	2.18	0.02	1.95	-0.23	0.22	-1.03	6	Vomiting
M	148	0.07	0.09	1.76	-0.02	1.98	0.21	0.29	0.75	7	Confusion
F	172	0.16	0.14	1.76	0.02	1.63	-0.13	0.20	-0.66	7	Confusion
M	148	1.15	1.03	-0.6	0.12	-0.75	-0.15	0.09	-1.61	8	Muscle weakness
F	172	0.86	0.96	-0.6	-0.10	-0.43	0.17	0.10	1.65	8	Muscle weakness
M	148	1.5	1.41	-1.07	0.09	-1.17	-0.11	0.09	-1.19	9	Heat sense
F	172	1.17	1.25	-1.07	-0.07	-0.96	0.11	0.10	1.18	9	Heat sense
M	148	0.11	0.10	1.64	0.01	1.58	-0.06	0.23	-0.26	10	Chills
F	172	0.16	0.16	1.64	0.00	1.67	0.03	0.20	0.16	10	Chills
M	148	0.25	0.26	0.81	-0.01	0.85	0.04	0.15	0.28	11	Giddiness
F	172	0.35	0.33	0.81	0.01	0.76	-0.05	0.14	-0.34	11	Giddiness

valid contrast, leaving 320 final data for analyses. The age of the respondents was between 19 to 64 years old with a mean (SD) of 43 (9.49) years old. Majority were aged between 40 and 49 years old (37.8%), female (53.8%), Indian (67.5%), had secondary education (56.3%), work as street cleaning (72.5%) and had adequate hydration (56.6%). The mean duration of service in the organisation was 51 months.

Unidimensionality of psychometric features

Point measure correlation and four fit statistic of items

A total of 3520 data points from 320 respondents based on 11 items were analysed. It yielded a log-likelihood χ^2 value of 4640.83 with 3187 degrees of freedom. There were no missing data in responses and removals of items were not required after 24 times of the iteration process.

Table I lists the eleven items of HRI symptoms in order of these verity estimates. Generally, the items have positive point measure correlation with a range of 0.40 to 0.81 logits. It has a smaller mean measurement error (SE = +0.10 logit) compared to hypothetical measurement error (SE= +0.34 logit) which is calculated by using formula 2.5/√total possible score of HRI symptoms. On two out of four fit indicators, symptoms of HRI confusion and lightheaded are erratic responses (underfit to the model) because both infit MNSQ and Zstd value are more than 1.4 and 2, respectively. These items may degrade the measurement performance. Item heat sense, thirst and feeling of tiredness, on the other hand, did well on three out of four fit indicators (only the respective infit Zstd value of -3.6, -3.1 and -4.1 are too erratic).

Principal Component Analysis (PCA) residuals

Table II shows the HRI symptoms measures are central and explained 70.8% of the variance in the data. The person measures show less variance in the data (20.3%) than the item measures (50.5%). This is probably because the person measure SD is smaller (SD=1.22) than the item measures SD (SD=1.51). In these data, the variance explained by the items, 50.5% is eleven times the variance explained by the first contrast. The 1st contrast in the "unexplained variance" (residual variance) has a size Eigenvalue of less than two items out of 11 items. It suggests that absent of substantive secondary dimension. It was further supported by a random pattern of standardised residual contrast 1 plot with few high loadings. So, there are no challenges to the evidence of unidimensionality of HRI symptoms.

DIF analysis to detect gender bias

Table III shows that all HRI symptoms are not gender biased. Vomiting for males (DIF measure =2.75 logits) seems higher logits than females (DIF measure=1.95 logits) which indicate the males are 0.80 logits experience more vomiting symptoms than the females. Although the DIF size of vomiting symptom is big enough to be noticeable for males i.e. 0.57 logits, the size is not significant enough not to have happened by chance (t-value=1.03). In addition, the average impact of biggest DIF on the person measures (DIF/number of items=0.57/11 =0.05 logits) is smaller than the measurement error of the person measures (SE=0.46 logits). These findings support evidence that potential source of gender bias in person measurement does not exist. Municipal workers of both genders have the same apparent level of ability to endorse a given eleven HRI symptoms correctly.

Person-Item map guiding threshold symptoms

Figure 1 shows the HRI symptoms are arranged by severity order on the right side, corresponding to the arrangement of persons on the left side. The left side of the map shows the distribution of the measured ability to experience HRI symptoms of the employees from more symptoms at the top to the least symptoms at the top. The items on the right side of the map are distributed from the least frequent items at the top to the most frequent at the bottom by the employees. A hierarchical correspondence between items and persons will show most frequent-to-endorse items accompanying persons with least symptoms of HRI and least frequent-to-endorse items accompany person with more symptoms of HRI symptoms. The person-item map of HRI symptoms can be separated into three levels by drawing four imaginary lines through mean item, mean person, maximum, and minimum item measures. The number of person strata is calculated by the following formula:

Person strata= (4*Person separation index + 1)/ 3

In this study, person separation index was 2.06, further implying that the instrument may be sensitive enough to distinguish persons into three strata i.e., mild, moderate and severe HRI symptoms. However, in this analysis, the person strata are viewed as two i.e., mild and moderate/severe of HRI symptoms so to ensure early preventative actions can be implemented. The thirst item was determined as threshold item at the cut-off point value of -2.17 logit. The decision was guided by the fact that thirst indicates the process of dehydration has just begun.7 Ignoring these critical physiological changes may lead to severe HRI symptoms development. Statistically, the difference of 1.1 logits between thirst item and heat sense item indicates clear separation of HRI severity symptoms for early preventative actions to prevent devastating outcomes such as heat exhaustion and heat stroke. Therefore, those persons scored HRI symptoms more than -2.17 logit were categorised as having moderate/severe HRI score whereas those scoring less than or equal to -2.17 logit are categorised as mild HRI.

DISCUSSION

This article aims to demonstrate that the representative HRI threshold symptom from mild to moderate or severe form of HRI as a platform to implement fast, yet simple preventative actions to be taken by the individual workers or the employers. On the one hand, thirst was statistically identified as the threshold symptom indicates that the process of dehydration has just begun. Dehydration occurs when as little as 2% loss of body weight resulting in impaired physiological responses and performance.[12] Thirst is the mechanism to overcome dehydration to initiate self-action to maintain body fluid balance and hydration. Theoretically, an increase in plasma osmolality of as little as one percent can stimulate the sensation of thirst[13] which is approximately 5mOsm/kg increment to 300mOsm/kg.[14] To stimulate thirst, osmoreceptor neurons in the anterior hypothalamus relay information to the cerebral cortex where thirst becomes a conscious sensation to initiate behavioural response to ingest adequate fluid to replenish water loss.[13,14] Ignoring these

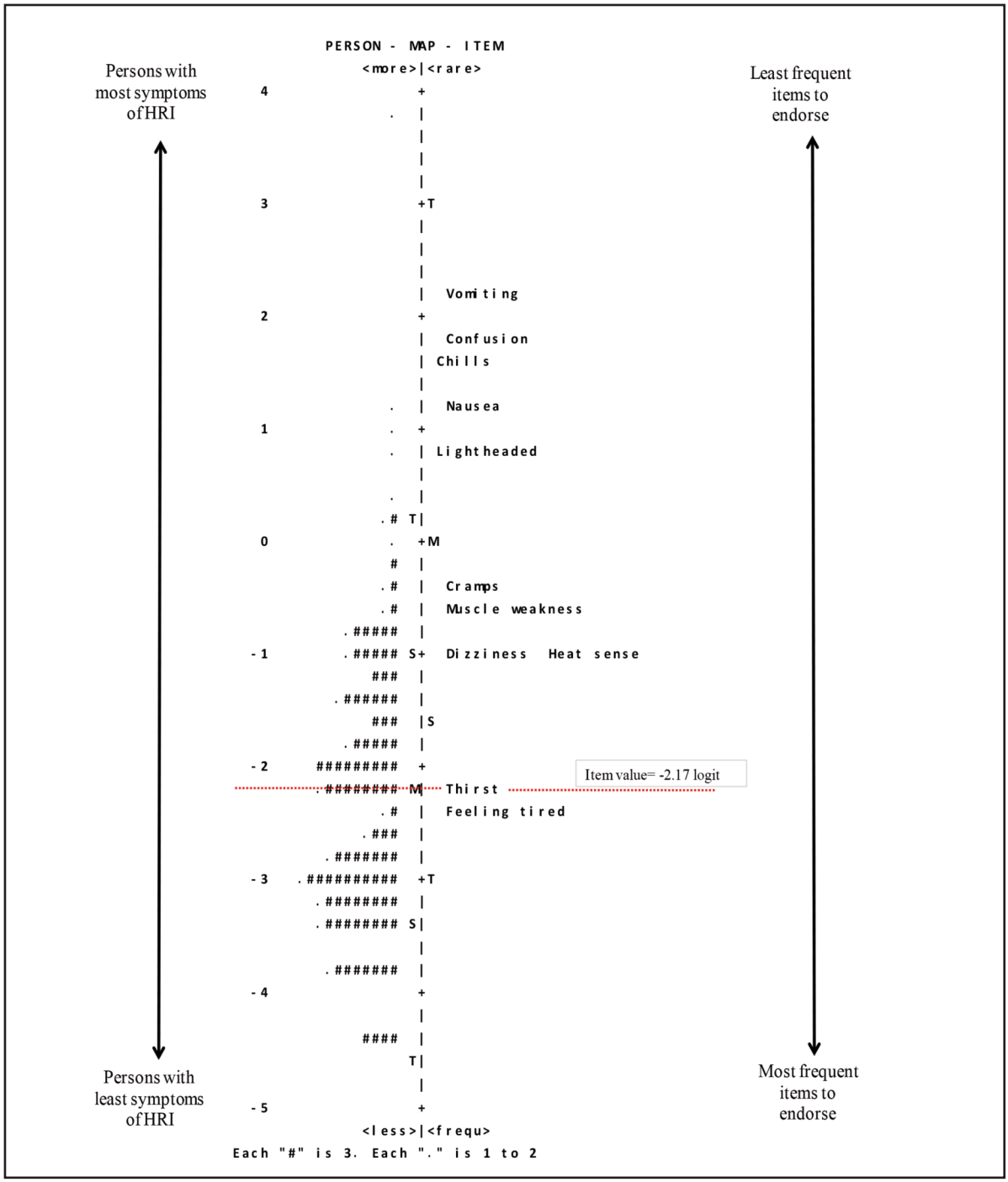

Fig. 1: Person-Item Map.

symptom may lead to worsening of dehydration that the increases risk to have severe consequences of heat exposure such as heat stroke.[15] This is because there is a delay of tens of minutes between the ingestion of water and its full absorption into the bloodstream. Drinking can quench thirst within seconds, long before the ingested water has had time to alter the blood volume or osmolality. Thus, thirst is not quenched by reversing the process that generates it; instead, the brain terminates thirst by using sensory cues from the oropharynx to track ongoing water consumption and then estimate how this water intake will alter fluid balance in the future, after the water has been absorbed.[13] Although providing zero calories, water is an essential element for cellular homeostasis and to ensure survival of the human body functions. It is involved in every biochemical reaction, playing a crucial role in digestion, the removal of waste products, thermoregulation, and the transportation, absorption, and dissolving of nutrients.[16]

Conversely, relying heavily on the thirst symptom may be a bad practice especially in older age group of more than 65 years old. They don't feel thirst until it is too late. This is

because older age group have a higher baseline osmolality and baroreceptor of volume stimulus is absent.[17] Therefore, older age groups have higher threshold of thirst sensation although the amount of daily fluid intakes should remain similar as younger age group.[18] Having said that, older age group are less likely to be hired as outdoor workers. They also have physiological changes due to factors in ageing, they are also prone to have medical conditions such as cardiovascular diseases that make them more vulnerable to have heat-related death.[19] In the United States, people aged 65 and above have been several times more likely to die from heat-related cardiovascular disease than the general population during summer (May to September) from year 1999 to 2014.[20]

There are many schools of thought pertaining to the adequate intake of water in daily life. Generally, the adequate intake of water for young men and women workers (ages 19 to 30 years old) is 3.7L and 2.7L per day, respectively.[21] The expected daily water turnover rates were approximately 3.2L and 4.5L for sedentary and active men, respectively while women had approximately 0.5L to 1.0L/day lower daily water turnover rates than their male counterparts.[22] The amount decreases with age. Apart from age, the minimal daily water requirement depends upon the person's diet, environmental heat exposure and activity level. The best person's diet practice is 20% of water comes from food and the remaining 80% comes from fluid (drinking water or other beverages). It is suggested for total water intake is 1mL/kcal expended[23] with minimum daily water requirements of no less than 0.91L for survival and 3.0 L for hot weather.24 In heat stress condition, the intake of water is increased up to 240ml every 15 to 20 minutes if the heat index is 39 to 46°C.[24] This translates to about 1L/hour. There is no upper limit of water intake but acute water toxicity can occur due to rapid consumption of large quantities of fluids that greatly exceed the kidney's maximal excretion rate of approximately 0.7 to 1.0 L/hour.[21] It is advisable for people not drink more than 1.4L/hour for those active outdoor workers in hot weather exposure because it can cause a medical emergency due to low concentration of salt in the blood.[25] Sport drinks that contain excess of caffeine compared to standard drinks and alcohol beverages should be avoided.

In this study, feeling of tiredness and thirst were the easiest items to endorse by the respondents. Other HRI symptoms (i.e., lightheaded, confusion, nausea, vomiting and chills) were not highly endorsed because they were representative manifestations of more severe HRI states such as heat stroke.[26] Residing in Malaysia, which is near the equator perhaps provide more opportunity to respondents to acclimatise according to baseline environmental ambient temperature as compared to those living in temperate countries. This study, however was done during the hottest month in the year 2016 when ambient temperature exceeded 36°C in most states in Malaysia, i.e., more than 10°C in the same month of time period 1991-2015,[27] before waning in late April 2016.[28] A total of 35 cases of HRI were recorded from 1st to 22nd March 2016, with five heat cramps, 25 heat exhaustion and five heat stroke cases. This included one policeman trainee who died due to heat stroke.[29] Although this number is far less compared to death due to other causes deaths,[30] the health impacts cannot be ignored as HRI are preventable.

CONCLUSION

Thirst items is viewed as transitional symptom between mild and moderate to severe HRI symptoms. It is a reliable symptom to initiate behavioural response to quench the thirst by drinking fluids adequately. Failure to recognise the thirst symptom may lead to serious health complications.

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