JEAS

JOURNAL OF ENGINEERING AND APPLIED SCIENCES

Journal of Engineering and Applied Sciences 12 (2018), 76-86

A physiological Assessment and Analysis of Stairs Climbing: Using the RAS and Efficiency of work done

Mbachu, Victor M.[1*] and Okonkwo Victor O.[2]
[1]Industrial and Production Engineering Department, Nnamdi Azikiwe University Awka, Nigeria
[2] Civil Engineering Department, Nnamdi Azikiwe University Awka, Nigeria
[*]Corresponding Author's E-mail: profvictor2000@yahoo.com

Abstract
Climbing the stairs up to a second floor of the engineering building in Nnamdi Azikiwe University in Awka, for classes has been a routine job for the students of Civil Engineering, and Industrial and Production Engineering departments. This they do as they rush to their classes for lectures, examination and other similar academic activities. The paper tries to assess the relative aerobic strain (RAS) on the students due to the climbing task at 3 different considered pace (causal walking (CW), keen fast walking (FW), and jogging (JG)). Also; the efficiency with which these tasks were carried out was analyzed. The result of the experiment on twenty-two (eighteen male and four female) normal healthy adults; within the age bracket of 19–26 years (mean = 23, SD = 2.064), and mean height and mass of 185.1 cm (SD 11.7) and 69.4 kg (SD 5.9) respectively; show that both the RAS and the efficiency increases as the pace of the tasks increases and vary from one individual to the other. Thus, in addition to some of the structural factors and aesthetics of design, fitness matching of individual to task with respect to RAS, as well as physiological efficiency of work should be considered when designing the stairs. Considering the result of the statistical analysis for correlation between pace and efficiency of work done; the design will have to incorporate features that will encourage the users to climb the stairs at relatively high pace for better efficiency.

Keywords: Ergonomics, Relative Aerobic Strain (RAS), Stair Design

1. Introduction

Human factors engineering (HFE) and ergonomics, which considers the functionality of designs as well as the users' comforts and safety while using the product or system, has been described as the engineering of user-friendly systems. It is the practice that takes into consideration the human factors in design of products, systems or processes with the aim of fitting man to the job and the job to the man towards the achievement of better system efficiency.

Ergonomic assessment and its impact analysis on the quality and productivity of products and systems have received wide interest from researchers. Robert et al (2012) in their research on improvement of safety and ergonomics in use of mechanical products, proposed a method that could proactively warn very early in the design process, the risk of causing Musculoskeletal Disorders (MSDs and facilitate optimization of the mechanical tool. Recently, Godwin and Okpala (2013) worked on ergonomic assessment of musculoskeletal disorders from load lifting activities in building construction. The research showed that adherence to the prescribed ergonomic standards in load lifting will lead to a significant decrease in weight and lifting indexes giving rise to enhanced good health for workers and overall system productivity. Jazani and Mousavi (2014) also carried out research on the impacts of ergonomics on the quality, considering the five areas of ergonomics (hardware, environmental, software, work design, and macro ergonomics). Their conclusion, not been different from others, supposed that ergonomic principles must be an integral component of an organizations' policy in order for it to reach acceptable quality standards.

Among the various classes of fatigue among college students put up by Schiffert Health Center in March 2010, Physiologic fatigue is the most common type found in the college student and usually due to overwork, lack of sleep, or a defined physical stress such as pregnancy. Healthy students with excessive or minimal exercise regimens are also affected. Stairs climbing is one of the various works done by the students as they come in for lectures at the second floor of the two-storey building.

Safety and comfort of the users should be a top priority in the goals for architects and engineers when designing buildings, especially the stairs. The trick is a balance of comfort and efficiency that satisfies the building code and enhances the architecture of the space.

Critical to stair design are the height of each riser and the width of each tread. All risers should be exactly or nearly the same height. Varying riser heights feel awkward and are difficult to ascend, because we need rhythm when we climb steps. Building codes also mandate equal heights, though slight variations are acceptable (Conrad and Winkel 1998). Various researches had been put up to enhance the safety of stair users. This ranges from cause – effect analysis of general design factors, layouts errors, user's attitudes, user's sensory limitations, to psychological state and behaviour of users. Karen (2014) examined contemporary practices in stairway design and their effects on the behaviour of stair users as it relates to safety of the system.

The incessant problem of fatigue among students in class was suspected to be partly due to the strenuous exercise of stair climbing before getting to the classrooms. Although the climbing of these stairs was seen as a gainful exercise by Samantha et al (2007); at some limit, this work could be seen as strenuous, unduly heavy, and perhaps detrimental to the students' wellbeing. They suggested that, stairs provide a ubiquitous and cost-effective opportunity to incorporate physical exercise into the daily routine.

Some stairways are easier to ascend than others, and there are reasons for that (Templer 1995). The parameters of stair design are set by building codes, and there are also recommended configurations based on average human proportions (Norman 2005).

There are, for example, tread-width-to-riser height relationships that make stairs more comfortable for the average person to traverse. Building codes set a minimum for staircase width, but wider dimensions are often necessary. Other important considerations are head clearance, railing dimensions and landings (Ricketts et al 2003, Madsen et al 2012).

The variations in the aerobic strains on the individual for various work rates are as a result varying energy demands by the muscles on the subject. The variation in energy demands is a function of forces/ loads to overcome (Costigan, Deluzio and Wyss, 2002). Mcfadyen and Winter (1988) found geometry of the stairs, powers, and moments at knee joint as factors influencing energy demand from subjects in stairs climbing. Costigan, Deluzio, and Wyss (2002), confirm the inclusion of powers and moments at knee joint as factors influencing energy demand from subjects in stairs climbing. Riener, Rabuffetti, and Frigo (2002) also observed the influence of moments on energy demand. More so, some researchers added angles of inclination and ranges of motion to the factors. Reid et al (2007) compared the kinematics and kinetics of the knee joint during traditional step-over-step (SOS) and compensatory step-by-step lead-leg (SBSL) and trail-leg (SBST) stair ambulation patterns.

This paper presents a simple experimental analysis of the physiological cost of such work on the student with respect to the relative aerobic strain and the physiological work efficiency for the 3 categories of motion with the aim of determining the optimum range of climbing pace and fitness of the student from human factor point of view.

It has been known that oxygen consumption rate, an indirect method of measuring energy expenditure by subjects, is very good. Literature provides various methods for measuring or estimating energy expenditure. They have also been analyzed to ascertain their pros and cons based on ease of use, cost, efficiency and accuracy. The proxy method of which heart beat rate belongs is considered cheaper and relatively fair in efficiency. Kelman et al (1989) pointed out that heart rate often correlates linearly and strongly with rate of energy expenditure during activity. Also heart rate methodology was used efficiently in Bedny, Karwowski and Seglin (2001) work in determining the cost-effectiveness of an ergonomic intervention to reduce workload and improve working conditions. Thus, this proxy method was considered and applied in this research.

2.0 Material and Methods

Twenty-two (eighteen male and four female) normal, healthy adults (with no history of chronic pain, major injury, or surgery to the lower limbs or back) participated in the study. They were within the age bracket of 19–26 years (mean = 23,SD = 2.064), and mean height and mass were 185.1 cm(SD 11.7) and 69.4 kg (SD 5.9), respectively. All

participants voluntarily nominated themselves for the test. The heartbeat rates were measured before and after the exercise with the stethoscope and stopwatch after the students have been trained on the procedure. The stairs were of standard dimensions, with each step being approximately 15 cm high and 26 cm deep, with a 26-cm tread which satisfies the condition in the guide for ergonomic notations by American Bureau of Shipping (2013).
The work rate at the various pace varies with individuals, with the mean value and standard deviation for the various pace (CW, FW, and JG) of 67.7(15.52), 139.8(48.01) and 211.6 (54.72) accents per minutes respectively.

2.1 Model Development and Computation

The relative aerobic strain is given by;

$$RAS = \frac{HBR_{WORK} - HBR_{REST}}{HBR_{MAX} - HBR_{REST}} \quad (1)$$

Where,

$$HBR_{WORK} = heartbeatratewhileworkorimmediatelyafterwork$$
$$HBR_{REST} = heartbeatratebeforeworkoratrestingposition$$
$$HBR_{max} = maximumexpectedheartbeatratewhichisafunctionofage.$$

For the purpose of these work the HBR_{max}model adopted from the Karvonen formula was used as shown below;

$$HBR_{max} = 220 - age \quad (2)$$

Using equation 1 and 2 above and the values of the $HBR_{REST} and HBR_{work}$measured during the experiment the RAS were computed and shown in the table 1;

The external work was calculated in joules (J).

External work was evaluated as the work done in lifting the body mass over the stair heights against gravitational force.

This was computed as product of the mass, acceleration due to gravity and the total height travel.

$$\text{External work} = MgH \quad (3)$$

Where, M = mass of the subject measured in Kg, g = acceleration due to gravity in m/s^2 and H = total height covered in m.

H= stair height * number of stairs climbed (4)

Since the students climbed the same number of stairs of same height under same gravitational effect, the defining variable of the external work done is their respective weight (mass). See table 2 for the values.

The physiological cost of work in joules is derived below

Based on caloric equivalent from experiment by Bar-Haim et al (2008)

5Kcal = 1 litre of O_2 consumption; and 1Kcal = 4186 J

Halsey, Watkins, and Duggan (2012) established the relationship between volume of 0_2 intakes and heart beat rates as;

$$VO_2 = 22.1 * \text{heart rate} - 1153.5 \quad (R^2 = 0.90) \quad (5)$$

But admitted that due to the variation in the relationship between individuals, heart-rate based prediction equations can only be used to predict heart rate in new individuals at the group level. That is, the above equation can only reasonably provide an estimate for the mean of a group of individuals (typically at least six). The present research is not actually on prediction of heartbeat rate.

The models below developed by Bar-Haim et al (2008) from an experiment conducted on similar sample and condition was used to determine the corresponding $ðVO_{22}$ for the samples and the various classes of task.

$$ðVO_2 = 252 + (7.14 * ðHBR) + (14.37 * wt) \qquad (6)$$

Thus,

Thephysiological cost of work

$$= ðVO_2\left(\frac{ml}{min}\right) * \left(\frac{L}{1000ml}\right) * \text{worktime (min)} * \frac{5Kcal}{L} * \frac{4186\ J}{Kcal} \qquad (7)$$

The efficiencies of the students in carrying the various classes of tasks were computed as;

$$\text{Work Efficiency} = \frac{\text{external work done}}{\text{physiological cost of work}} * 100 \qquad (8)$$

Table 2 has the values of the computed work efficiency and the corresponding RAS for analysis.

3.0 Results

The tables 1 and 2 gave observed and computed values of data generated from the experiment for all the subjects that participated for various classes of work in the experiment.

The Relative Aerobic Strain (RAS) was computed from the observed data inputted in equations (1) and (2). The external work, volume of O_2 intakes, physiological (internal) cost of work, and work efficiency were computed from the observed data inputted in equations (3), (5), (7) and (8) respectively.

Table 1: Demographic Data of Subjects, Observed Values and Computed RAS for the Subjects.

Subject	**Age** (years)	**SEX**	**HBR_{max}**	**Class of Work**	**HBR_{rest}** (per min)	**WORK Duration** (min)	**WORK RATE** (ascents/min)	**HBR_{work}** (per min)	**RAS** (%)
1	26	M	194	CW	90	0.65	73.85	98	7.69
	26		194	FW	91	0.28	169.61	117	25.24
	26		194	JG	93	0.17	287.43	123	29.70
2	19	F	201	CW	75	0.50	96.00	80	3.97
	19		201	FW	77	0.25	192.00	85	6.45
	19		201	JG	76	0.18	262.30	95	15.20
3	24	M	196	CW	66	0.68	70.28	78	9.23
	24		196	FW	64	0.25	192.00	80	12.12
	24		196	JG	65	0.17	282.35	89	18.32
4	25	M	195	CW	72	0.55	87.27	80	6.50
	25		195	FW	78	0.42	115.12	112	29.06
	25		195	JG	80	0.37	130.79	114	29.57
5	21	M	199	CW	72	0.63	75.83	79	5.51

Subject	Age (years)	SEX	HBR_{max}	Class of Work	HBR_{rest} (per min)	WORK Duration (min)	WORK RATE (ascents/min)	HBR_{work} (per min)	RAS (%)
	21		199	FW	70	0.23	206.01	97	20.93
	21		199	JG	78	0.18	262.30	112	28.10
6	20	M	200	CW	82	0.63	75.83	91	7.63
	20		200	FW	95	0.23	206.01	111	15.24
	20		200	JG	98	0.18	262.30	120	21.57
7	23	M	197	CW	72	1.33	36.00	78	4.80
	23		197	FW	80	0.67	72.00	98	15.38
	23		197	JG	82	0.33	144.00	102	17.39
8	22	F	198	CW	74	1.12	43.00	78	3.23
	22		198	FW	86	0.58	82.29	96	8.93
	22		198	JG	80	0.30	160.00	104	20.34
9	26	M	194	CW	70	1.08	44.31	80	8.06
	26		194	FW	88	0.58	82.29	98	9.43
	26		194	JG	108	0.28	169.41	120	13.95
10	24	M	196	CW	90	0.79	61.15	98	7.55
	24		196	FW	91	0.51	94.74	116	23.81
	24		196	JG	92	0.27	175.61	127	33.65
11	21	M	199	CW	66	0.70	68.57	75	6.77
	21		199	FW	68	0.52	92.84	85	12.98
	21		199	JG	69	0.30	160.00	90	16.15
12	23	M	197	CW	70	0.77	62.47	80	7.87
	23		197	FW	72	0.48	99.31	84	9.60
	23		197	JG	74	0.27	177.78	99	20.33
13	20	M	200	CW	81	0.88	54.50	88	5.88
	20		200	FW	71	0.47	103.20	87	12.40
	20		200	JG	75	0.30	160.00	103	22.40
14	23	F	197	CW	95	0.63	75.80	98	2.94
	23		197	FW	110	0.32	150.00	116	6.90
	23		197	JG	117	0.22	218.20	123	7.50
15	26	M	194	CW	90	0.79	61.10	98	7.69
	26		194	FW	91	0.52	92.30	116	24.27
	26		194	JG	92	0.27	177.80	127	34.31
16	21	M	199	CW	82	0.88	54.36	87	4.27
	21		199	FW	72	0.47	102.86	88	12.60
	21		199	JG	76	0.31	156.42	104	22.76
17	22	M	198	CW	80	0.80	60.00	86	5.08
	22		198	FW	77	0.42	115.20	94	14.05
	22		198	JG	72	0.28	169.44	98	20.63
18	25	F	195	CW	114	0.63	75.78	119	6.17
	25		195	FW	110	0.32	151.56	125	17.65
	25		195	JG	108	0.22	221.52	130	25.29
19	22	M	198	CW	68	0.68	70.24	80	9.23

Subject	Age (years)	SEX	HBR_{max}	Class of Work	HBR_{rest} (per min)	WORK Duration (min)	WORK RATE (ascents/min)	HBR_{work} (per min)	RAS (%)
	22		198	FW	66	0.25	192.00	82	12.12
	22		198	JG	67	0.17	288.00	91	18.32
20	22	M	198	CW	88	0.63	75.79	96	7.27
	22		198	FW	90	0.27	180.00	116	24.07
	22		198	JG	93	0.17	288.00	122	27.62
21	26	M	194	CW	74	0.50	96.00	80	5.00
	26		194	FW	76	0.25	192.00	86	8.47
	26		194	JG	78	0.18	261.82	96	15.52
22	23	M	197	CW	68	0.68	70.24	78	7.75
	23		197	FW	62	0.25	192.00	80	13.33
	23		197	JG	65	0.20	240.00	89	18.18

Table 2: Table Showing Class of Work, Mass of Subjects, Computed Work done, V_{O2} Intake and Work Efficiency for various Subjects

Subjects	Class Of Work	RAS	Mass of Subject (Kg)	External Work (Joule)	Internal Energy Cost (Joule)	V_{o2} Estimation	Work Efficiency
1	CW	7.69	78.0	5509.30	19454.16	1429.98	28.32
	FW	25.24		5509.30	9231.29	1558.50	59.68
	JG	29.70		5509.30	5547.27	1587.06	99.32
2	CW	3.97	73.0	5156.14	13988.67	1336.71	36.86
	FW	6.45		5156.14	7106.42	1358.13	72.56
	JG	15.20		5156.14	5502.72	1436.67	93.70
3	CW	9.23	75.0	5297.40	20233.84	1415.43	26.18
	FW	12.12		5297.40	7555.68	1443.99	70.11
	JG	18.32		5297.40	5341.10	1501.11	99.18
4	CW	6.50	75.5	5332.72	16047.66	1394.06	33.23
	FW	29.06		5332.72	13787.28	1579.70	38.68
	JG	29.57		5332.72	12134.13	1579.70	43.95
5	CW	5.51	76.5	5403.35	18565.19	1401.29	29.10
	FW	20.93		5403.35	7530.02	1544.09	71.76
	JG	28.10		5403.35	6105.57	1594.07	88.50
6	CW	7.63	68.5	4838.29	17231.31	1300.61	28.08

Subjects	Class Of Work	RAS	Mass of Subject (Kg)	External Work (Joule)	Internal Energy Cost (Joule)	V_{o2} Estimation	Work Efficiency
	FW	15.24		4838.29	6586.38	1350.59	73.46
	JG	21.57		4838.29	5337.08	1393.43	90.65
7	CW	4.80	69.9	4937.18	36259.22	1299.30	13.61
	FW	15.38		4937.18	19325.13	1384.98	25.55
	JG	17.39		4937.18	9762.19	1399.26	50.57
8	CW	3.23	74.0	5226.77	31410.34	1343.94	16.64
	FW	8.93		5226.77	16931.43	1386.78	30.87
	JG	20.34		5226.77	9335.24	1486.74	55.99
9	CW	8.06	74.0	5226.77	31444.08	1386.78	16.62
	FW	9.43		5226.77	16931.43	1386.78	30.87
	JG	13.95		5226.77	8308.52	1401.06	62.91
10	CW	7.55	74.0	5226.77	22550.24	1372.50	23.18
	FW	23.81		5226.77	15841.90	1493.88	32.99
	JG	33.65		5226.77	8954.76	1565.28	58.37
11	CW	6.77	73.0	5156.14	20002.57	1365.27	25.78
	FW	12.98		5156.14	15391.41	1422.39	33.50
	JG	16.15		5156.14	9110.52	1450.95	56.60
12	CW	7.87	69.0	4873.61	21145.67	1314.93	23.05
	FW	9.60		4873.61	13446.51	1329.21	36.24
	JG	20.33		4873.61	8036.03	1422.03	60.65
13	CW	5.88	78.0	5509.30	26228.29	1422.84	21.01
	FW	12.40		5509.30	14476.75	1487.10	38.06
	JG	22.40		5509.30	9875.49	1572.78	55.79
14	CW	2.94	65.0	4591.08	16003.60	1207.47	28.69
	FW	6.90		4591.08	8230.61	1228.89	55.78
	JG	7.50		4591.08	5658.08	1228.89	81.14
15	CW	7.69	69.0	4873.61	21386.01	1300.65	22.79

Subjects	Class Of Work	RAS	Mass of Subject (Kg)	External Work (Joule)	Internal Energy Cost (Joule)	V_{o2} Estimation	Work Efficiency
	FW	24.27		4873.61	15478.10	1422.03	31.49
	JG	34.31		4873.61	8438.47	1493.43	57.75
16	CW	4.27	61.0	4308.55	21517.15	1164.27	20.02
	FW	12.60		4308.55	12138.84	1242.81	35.49
	JG	22.76		4308.55	8532.50	1328.49	50.50
17	CW	5.08	71.0	5014.87	22020.20	1315.11	22.77
	FW	14.05		5014.87	12153.79	1393.65	41.26
	JG	20.63		5014.87	8644.21	1457.91	58.01
18	CW	6.17	59.0	4167.29	15054.09	1135.53	27.68
	FW	17.65		4167.29	8000.33	1206.93	52.09
	JG	25.29		4167.29	5700.35	1256.91	73.11
19	CW	9.23	70.0	4944.24	19216.11	1343.58	25.73
	FW	12.12		4944.24	7179.72	1372.14	68.86
	JG	18.32		4944.24	4985.74	1429.26	99.17
20	CW	7.27	65.0	4591.08	16479.05	1243.17	27.86
	FW	24.07		4591.08	7655.86	1371.69	59.97
	JG	27.62		4591.08	4859.63	1393.11	94.47
21	CW	5.00	59.0	4167.29	11958.04	1142.67	34.85
	FW	8.47		4167.29	6128.46	1171.23	68.00
	JG	15.52		4167.29	4713.38	1228.35	88.41
22	CW	7.75	60.0	4237.92	16956.65	1185.60	24.99
	FW	13.33		4237.92	6502.53	1242.72	65.17
	JG	18.18		4237.92	5381.35	1285.56	78.75

4.0. Analysis of Results

Evaluation of mechanical efficiency of the individual, which is given by percentage of the ratio of external work done (in joules) to the energy expended by the body (in joules) in response to the external work as well as internal body metabolism, was done.

External work done in climbing the stairs = $\sum potential\ energy + kinetic\ energy$

Where PE is used to lift the feet (the body) against gravity and KE takes account the rate of the climbing.
From equations (3), (6), (7) and (8), the mechanical efficiency of each individual for each task is a function of the mass of the individual, the geometry of the stairs, and the physiological cost on the individual. The physiological cost of the individual is a function of the intensity of the task, the fitness of the individual among other factors.

The table 3 shows that the correlation between mass of the students and work efficiency is weak and negative, but that of mass of the students and RAS is weak but positive for all classes of work. The result shows that, although the mass of the subject contributes to the efficiency and RAS, there are other stronger factors that influence the efficiency with which these tasks were carried out, as well as the physiological cost with respect to RAS.

From the result in table 2: the jogging pace gave the highest efficiency for each individual, just like the paradox of the richer paying less with respect to unit cost due to bulk purchase. It was also observed that the RAS increases as the pace increases, and varies among individuals. The RAS ranges from 2.94 to 34.31 across the 22 subjects and 3 different work rates.

Table 3: Coefficient of Correlation and Determination between Work Efficiency, RAS and Mass of Student

	Between mass of the students and work efficiency				Between mass of the students and RAS		
	CW	FW	JG		CW	FW	JG
correlation coefficient	-0.123	-0.172	-0.082		0.165	0.229	0.230
coefficient of determination	0.015	0.030	0.007		0.027	0.052	0.053
	1.5%	3.0%	0.7%		2.7%	5.2%	5.3%

Table 4: Coefficient of Correlation and Determination between Work Efficiency, RAS and Work Rate

	Between Work Rate and Work Efficiency	**Between Work Rate and RAS**
Coefficient of Correlation	0.996413	0.599163
Coefficient of Determination	0.992838	0.358996
Coefficient of Determination (%)	99.28%	35.90%

From the table 3, the mass of the students and the work efficiency gave consistently a negative correlation value for all the paces considered, while the RAS increases as the mass increases for various paces considered. This implies that likely students with smaller mass will perform better and with lesser strain. Although the percentage of change in efficiency and RAS that could be attributed to change in mass is quite low, the cause – effect analysis will involve mass alongside other prevalent factors.

Table 4, shows a very strong positive correlation between the work rate and the efficiency. Also, the high coefficient of determination shows that work rate is majorly responsible for the efficiency. The RAS on the other hand increases as the work rate increase with the work rate responsible for just 35.9% of the variations in the RAS. Thus, there exist other factors (age, physiological condition of the individual, experience, cardiovascular condition of the individual etc.) that influence the RAS of the individual. While increase in the efficiency is desirable, the observed increase in the RAS as the pace increases is an undesirable phenomenon. Therefore, the design of the stair should be one that will influence the user rate (speed) in the positive sense of it, but the optimum work rate will be obtained from a prudent trade-off between efficiency and RAS.

Table 5: The mean values and standard deviation of the work efficiency and RAS for the three categories of work rate considered.

	Work Efficiency				**RAS**		
	(CW)	**(FW)**	**(JG)**		**(CW)**	**(FW)**	**(JG)**
Average	25.32	49.66	72.61		6.37	15.23	21.67
Standard Deviation	5.64	16.59	18.43		1.78	6.41	6.57

From table 5, it could be deduced that the work efficiency of FW (approx. 50%) is the basic level for recommendation during the stair climbing exercise. The jugging pace of an average speed of 211.6 (SD: 54.72) accents per minutes respectively could be recommended with an average efficiency of 72.6% and RAS of 21.67(still within the acceptable frame for such class of work).

5.0. Conclusion

Based on the result obtained from the experiment and the analysis carried out, it was deduced that the current design of the stair way is within the acceptable geometry, considering the physiological strain on the users not minding the pace. For higher efficiency which is achieved during the fast walking pace and jogging pace, the RAS in some of the students went as high as 29 to 32. Thus, there is therefore a need to have a trade-off between achieving higher efficiency and less strain on the worker. From the experiment, it could be deduced that the work efficiency of FW (approx. 50%) will be seen as the basic level for recommendation during the stair climbing exercise. The jogging pace of an average speed of 211.6 (SD: 54.72) accents per minutes, having an average efficiency of 72.6% and RAS of 21.67was seen as the optimal pace where efficiency maximization is the basic objective function. Finally, there is need for consideration of physiological cost on users and user's work efficiency in the design of stair ways.

References

1. American Bureau of Shipping, 2013. *Guide for Ergonomic Notations*. Houston, American Bureau of Shipping TX 77060 USA

2. Bar-Haim, S., Belokopytov, M., Harries, N., Loeppky, J. A., Kaplanski, J., 2008. *Prediction of mechanical efficiency from heart rate during stair-climbing in children with cerebral palsy* Gait and Posture, 27 pp 512–517

3. Bedny G. Z., Karwowski W, Seglin M. H., 2001. *A Heart Rate Evaluation Approach to Determine Cost-Effectiveness an Ergonomics Intervention*. International Journal of Occupational Safety and Ergonomics, 7(2) pp 121–133.

4. Conrad R. T. Winkel S. R., 1998. *Design Guide to the 1997 Uniform Building Code*, John Wiley and Sons, USA.

5. Costigan, P. A., Deluzio K. J., and Wyss U. P., 2002. *Knee and hip kinetics during stair climbing*. Gait Posture, 16 pp 31–37.

6. Godwin H. C. and Okpala C.C., 2013. *Ergonomic Assessment of Musculoskeletal Disorders from Load-Lifting Activities in Building Construction*, International Journal of Advance Engineering Technology., 4(3) pp 15-23

7. Halsey, L. G., Watkins, D. A. R., and Duggan B. M., 2012. *The Energy Expenditure of Stair Climbing One Step and Two Steps at a Time: Estimations from Measures of Heart Rate PLoS One*.; 7(12): e51213. Published online 2012 December 12. doi: 10.1371/journal.pone.0051213

8. Jazani, R. K. and Mousavi, S., 2014. *The Impact of Ergonomic Aspects on the Quality*, Open Journal of Safety Science and Technology, 4, 15-21. http://dx.doi.org/10.4236/ojsst.2014.41003

9. Kelman, G. J., Biden, E. N., Wyatt, M. P., Ritter, M. A., Colwell, C. W., 1989. *Gait Laboratory Analysis of a Posterior Cruciatesparing Total Knee Arthroplasty In Stair Ascent And Descent*. Clin. Orthop. Relat. Res. 284 pp 21–26

10. Kim, K., 2014. *Contemporary Practices in Stairway Design: Behavior of Stair Users in Public Buildings*; MSc Thesis submitted to the Department of AJChitecture of the University at Buffalo, State University of New York. Microform Edition © ProQuest LLC (UMI 1553047), USA.

11. Madsen, D. A., Madsen, D. P., 2012. *Engineering Drawing and Design*, Cengage Learning Delmar USA

12. Mcfadyen, B., Winter, D. A., 1988. *An integrated biomechanical analysis of normal stair ascent and descent*. J. Biomech, 24 pp 733– 744

13. Neufert, E., Neufert P., Kister J., 2012. *Architects' Data*, John Wiley and Sons USA

14. Norman, J., 2005. *Fire Officer's Handbook of Tactics*, PennWell Corporation USA

15. Reid, S. M., Lynn, S. K., Musselman, R. P., Costigan, P. A., 2007. *Knee Biomechanics of Alternate Stair Ambulation Patterns.* Med. Sci. Sports ExeJC., 39(11) pp. 2005–2011,

16. Ricketts, J., Merritt, F., 2003., *Standard Handbook of Civil Engineers*, McGraw Hill Professional USA

17. Riener, R., Rabuffetti, M., Frigo, C., 2002. *Stair ascent and descent at different inclinations*. Gait Posture, 15 pp 32–44.

18. Robert, A., Roth, S., Chamoret, D., Yan, X., Peyraut, F., Gomes, S., 2012. *Functional design method for improving safety and ergonomics of mechanical products*. J. Biomedical Science and engineering, 5, pp 457-468. http://www.SciRP.org/journal/ jbise/)

19. Samantha, R. M., Scott, L. K., Reilly, M. P., Patrick, C. A., 2007. *Knee Biomechanics of Alternate Stair Ambulation Patterns* Journal of the American College of Sports Medicine pp (2005-2011)

20. Schiffert Health Center, 2010. *Fatigue and the College Student*. www.healthcenter.vt.edu Revised Edition.

21. Templer, J. 1995. *The Staircase: Studies of Hazards, Falls and Safer Design*, MIT Press USA.