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Improving Domestic Ergonomics: A Fuzzy-Based Model Approach

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Abstract: In this study a fuzzy logic model was adopted to assess the degree of Domestic Ergonomic Hazards (DEH) among women in the Southwest Nigeria. Three risk factors of weight (Kg), height of load (cm) and the handlers' arm reach (cm) were used. The leading objective was to provide an improved assessment ergonomics tool to Risk Assessment Filter (RAF). The algorithm of the fuzzy inference engine applied sets of 64 linguistic rules to generate the output variable in lifting/lowering risk. The Spearman's rank correlation value of 0.85 at the confidence level of 0.01, indicated no significant difference between the human predictions of DEH with the use of RAF tool and the model's predictions. The risk values and interpretations generated by the model were confirmed not just similar to, but with better information than, using RAF. The study proposed a fuzzy-based model for an enhanced domestic ergonomics among women than using RAF device. It is simple and can find its usefulness in household chores.

Keywords**:** domestic, ergonomics, hazards, women, fuzzy, model.

1. Introduction

Lifting, as defined by NIOSH [1], is a forceful movement requiring energy and muscle effort which stresses muscles, tendons and ligaments and increases forces on the spine. Lifting operations typically entail some risk factors that cannot be totally eliminated. In fact, no manual handling activity is completely safe. The physically demanding nature helps explain why strains and sprains are the most common type of injury among the group of workers involving in lifting related jobs. Lifting task may be considered hazardous if the imposed loads (forces) exceed the individual's strength and tolerance. Whereas the risk of injury is largely determined by the weight lifted. Hence, the amount of weight being lifted from floor level or above shoulder should be reduced and at neutral posture (body not twisted). Keeping arms fully extended, for instance, when lifting heavy loads may strain the forearm muscles. In a similar manner, holding objects at arm's length can also increase the load on the lower spine by 15 times the original weight. It is therefore safer to hold the object as close to handlers' body as possible to reduce the strain on arms and back [2-6].

Among the womenfolk, low back disorders are the most vital reported problem for those who work at construction sites and in industries where series of lifting related tasks are carried out. This has the tendency to influence the quality of work and health of female workers [7]. According to WHO [8] women, on the average, make up about 42% of the estimated global paid labour force population, making them indispensable contributors to national economies. In the developing countries, it is taken for granted that women will do most heavy lifting and carrying. In Nigeria, there are only few women in formal labour force [9].

Most women are involved in daily paid work and some of them are into lifting related, most especially in construction industry. Even at home where women tend to work more hours to make up the primary responsibility for family well-being, several casual lifting are engaged. Women's average lifting strength is only 50% of men's. Meanwhile physical load may exert greater strain on the average. Women are therefore more often exposed to some physical risks factors such as; repetitive movements, material lifting and awkward postures among others.

As part of its many efforts at helping employers, managers, safety officers, safety representatives, employees and others reduce the risk of injury from manual lifting, Risk Assessment Filter (RAF) relevant to: lifting and lowering; carrying for short distances; pushing and pulling; and handling while seated was developed by HSE [10].Using the filter, the guideline in Figure 1 helps to assess the task. It was however stretched that a more detailed assessment is necessary if: using the filter shows the activity exceeds the guideline figures; the activities do not come within the guidelines; there are other considerations to take into account; the assumptions made in the filter are not applicable; for each task the assessment cannot be done quickly. However for time or effort saving, it was stated that it may be better to opt immediately for the more detailed risk assessment. A full assessment of every manual handling operation however could be a major undertaking and might involve wasted effort [10]. Hence the need for more automatic, less human involvement and more detailed risk assessments tools that will allow expertise input into design process of which this study set out to achieve.

This study developed and validated a model capable of assessing the severity of injury risks involved in lowering and lifting operations carried out by Nigeria women. The objectives are to: provide an improved and less human involvement assessment tool to RAF; provide more information on the severity of injury risk involved in lifting/lowering operatios than may be achieved using RAF and; minimize injuries among women in household chores and other lifting related jobs.

Fig. 1 Areas around the body within which loads may be lifted without risk for 95% of the Female population [11].

2. Materials and Methods

2.1 Selection of lifting tasks and collection of variables for the model development. In this study, three input variables were used. These variables are the major factors mentioned in lifting and lowering RAF guidelines. These include "weight", "handler height" and "handler arm reach". The applicable tasks considered were those based on; the load that is easy to grasp with both hands; the lifting operation that takes place in reasonable working conditions; and the handler in a stable body position [10]. The output variable, lifting/lowering injury risk was determined by fuzzy logic.

2.2 Fuzzy Logic. Fuzzy Logic algorithm was adoped in this study. The tool consists of heuristics rules that define the parameters of the focal problem. These include: data base, fuzzy rule base, fuzzy inference machine and defuzzification. Fuzzy Logic is applicable to artificial intelligence, control engineering, and expert systems [12]. The technique is functional in a wide range of applications designed to model the problem solving ability of a human experts. It imitates the logic of human thought and how a person would make decisions, only much faster [13]. Fuzzy logic was widely used when human evaluations and the modelling of human knowledge in risk assessment are needed [14,15]. Among many recent attempts with the use of fuzzy tool in risk assessments; [16] presented an adaptive neuro-fuzzy inference system to estimate maximum forces and moments being generated at the hip joint during lifting tasks using the duration of the lift, the height and mass of the subject, and the load as input variables; A fuzzy logic was adopted by Jelena and Dagan [17] for practical risk assessment of bridges under different hazards using the identified risks as input variables and bridge damage level as the output variable; Adeyemi et al., [18] developed a fuzzy-based expert system called the Pain Intensity Prediction Expert System (PIPES) to predict pain severity risk in shoveling-related tasks using scooping rate, scooping time, shovel load, and throw distance as input variables. An expert system called Musculoskeletal Disorders – Risk Evaluation Expert System (MSDs-REES) capable of assessing risk associated with manual lifting in construction tasks and proffer some first aid advices was earlier developed by same author using load, posture and frequency of lift as inputs and risk of low back pain as the output [19].

The fuzzyrules used were that of linguistic and in the form of "IF-THEN". According to Yager et al. [20], fuzzy IF-THEN rules allow to evaluate good approximations of desired attribute values in a very efficient way. It allows available experts' knowledge to be included. A single if-then rule assumes the form 'if x is Athen y is B'. The if-part of the rule 'x is A' is the premise, while the then-part of the rule 'y is B' is the conclusion [21].

2.3 Domestic Ergonomic Hazards (DEH) evaluation with fuzzy logic model. There are three steps involved in the development of the DEH evaluation model:

2.3.1 Fuzzification of input variables and output risk values. There are three general types of fuzzifiers to associate a grade to linguistic term, singleton fuzzifier, Gaussian fuzzifier and trapezoidal or triangular fuzzifier [22]. The data used in this model are vague, hence they were converted into fuzzy numbers. The crisp variables were transformed into grades of membership for linguistic terms of fuzzy sets. Intervals of 'handlers height' and 'arm reach' linguistic variables were carefully set, by the author, using lifting and lowering RAF guidelines. The female anthropometrical parameters of the variables were drawn from other authors and were modified to form the intervals. Sources of which include the reported; average female arm length of 67.725 (11.38) [23], forearm-hand length and upper arm of 45,00 (3.08) cm and 31cm (3.45) respectively [24], popliteal height of 47.7 (3.5) cm [25], Knee height of 56.9(3.1) [26], average standing shoulder height of 129.1(4.92) [27]. The weight classification linguistic variable was a modified version of the study results relating guidline weigth for lifting and lowering [10]. The output variable, risk level, was developed from the expert knowledge reported by Adeyemi et al., [19]. The numbers of MFs were determined by the author as well as the baselines. The researcher developed the system linguistic terms and intervals by detailing four linguistic terms to all the three input and the output variables as shown in Tables 1 to 4. Figure 2 to 5 are all the MFs for the input and output variables.

Table 1 Fuzzy set of input variable 'Handlers' height'

Linguistic Terms	Interval
Shoulder height (SH)	99.6,128.2,130.2,133
Elbow height (EH)	61.5, 98.1, 99.6, 128.2
Knuckle height (KH)	30.75,54.4,61.5, 98.1
Mid lower leg height (MLH)	0,27.2, 30.75, 54.4

Modified version of the study results relating Anthropometry of South Eastern and South Western Females in Nigeria [26,27]

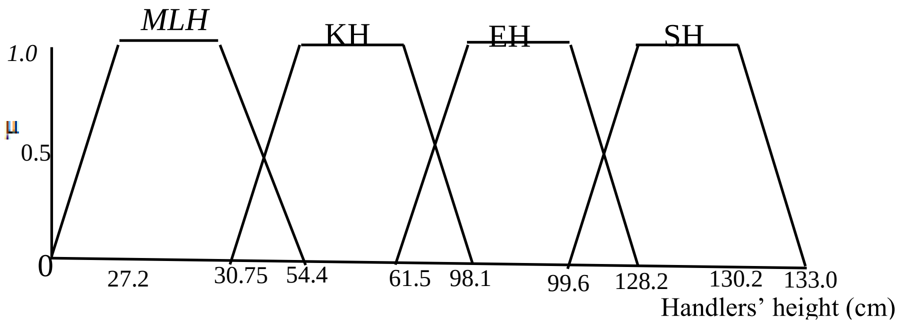

Fig. 2 All membership functions for the input variable 'Handler's height'

Table 2 Fuzzy set of input variable 'Weight'

Linguistic Terms	Interval
No load (NL)	0,0,0,0
Light load (LL)	0,3,5,7
Midium load (ML)	5,7,10,13
Heavy load (HL)	10,13,16,25

Modified version of the study results relating guideline weight for lifting and lowering [10]

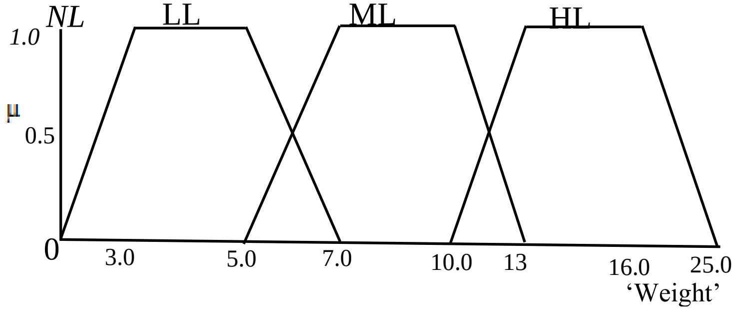

Fig. 3 All membership functions for the input variable 'Weight'

Table 3 Fuzzy set of input variable 'Handlers' reach'

Linguistic Terms	Interval
No movement (NM)	0,0,0,0
Low arm movement (LAM)	0,20,30,36
Normal arm movement (NAM)	30, 36, 45, 60
Extended arm movement (EAM)	45, 60,76, 85

Modified version of the study results relating anthropometric parameters of South South and South West, Nigeria [24,28]

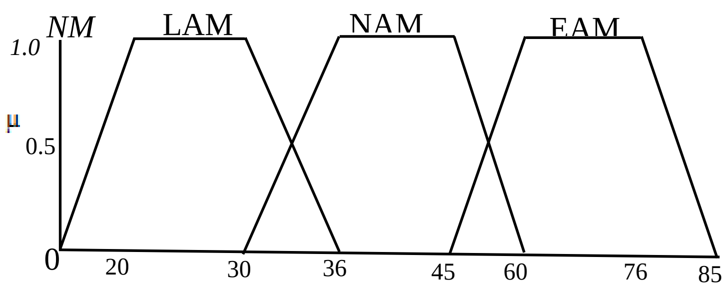

Fig. 4 All membership functions for the input variable 'Handler's reach'.

Table 4 Fuzzy set of output variable 'Lifting/Lowering Risk'

Linguistic Terms	Interval
No risk (NR)	0,0,0,0
Low risk (LR)	0,0,1,1.1
Medium risk (MR)	1,1.1,2,2.1
High risk (HR)	2,2.1,3,3.1

Adeyemi et al., [19]

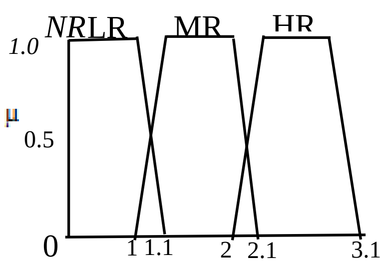

Fig.5 All membership functions for the output variable 'Lifting/Lowering Risk'

2.3.2. Determination of application rules and inference method A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. The relationship between heuristic, input and output parameters enabled the formation of 'If Then Rules'[29]. With the three inputs used in this study and each having four (4) variables, a rule base matrix, size of 4^3 resulting in total sets of 64 matrices were achievable. The rules were "fired" by Mamdani's fuzzy inference method-the most commonly seen fuzzy methodology. The technique is intuitive, has widespread acceptance and is well-suited to human inputs [30].

The following rules show only a portion of the 64 possible linguistic rules designed and fired into the inference engine of the model:

- 1. If (HandlerHeigth is MLH) and (Weigth is NL) and (HandlerReach is NM) then (LiftingRelatedRisk is NR)
- 3. If (HandlerHeigth is MLH) and (Weigth is ML) and (HandlerReach is NM) then (LiftingRelatedRisk is LR)
- 19. If (HandlerHeigth is MLH) and (Weigth is ML) and (HandlerReach is LAM) then (LiftingRelatedRisk is MR)
- 48. If (HandlerHeigth is SH) and (Weigth is HL) and (HandlerReach is NAM) then (LiftingRelatedRisk is HR)
- 64. If (HandlerHeigth is SH) and (Weigth is HL) and (HandlerReach is EAM) then (LiftingRelatedRisk is HR)

2.3.3. Defuzzification of risk value. Defuzzificcation converts the fuzzy value obtained from composition into a “crisp” value. This process is often complex since the fuzzy set might not translate directly into a crisp value. Two of the more common defuzzificationtechniques are the centroid and maximum methods [31]. In the centroid method used in this model, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function for the fuzzy value.

2.4 Model implimentation. The model,DEH,was implemented in MATLAB®. MATLAB provides symbolic solution and a visual plot of result [32] and creation of user interfaces [33]. For each case, all the three variables were fuzzified by the application. Active MF were calculated according to rule table. The output, lifting/lowering risk, was defuzzified by calculating the center (centriod) of the resulting geometrical shape. This sequence was repeated for each scenario of lifting and/or lowering operations.

2.5 Model Validation. Three professionals qualified in the field of ergonomicsfrom academics environment drew out 16 scenarios and possible cases values using the lifting and lowering RAF and linguistic risk conclusions were drawn. The same variable values were run by the model to generate risk values and risk level predictions. The linguistic risks predicted by assessors using RAF were compared with that of the model.

For statistical confirmation, Spearman’s Rank Correlation (SRC) coefficient was used. The RAF prediction which whichwas presented either “injury not likely” or “injury likely” were ranked “0” and “1” respectively. The model predictions were also categorized into two; those with “no risk” and those with “one level of risk or the other”. These two categories were equally ranked “0” and “1” respectively. SRC was used to ascertain the strength of relationship between the two sets of data at the confidence level of 0.01. The SRC significance table was used to verify the significance of their relationship. Spearman's rank correlation coefficient (r_s) is a reliable and fairly simple method of testing both the strength and direction (positive or negative) of any correlation between two variables [34].

3. Results and Discussion

Cases	Measurement						HSE	Model	
	MLH (cm)	KH (cm)	EH (cm)	SH (cm)	Weigth (Kg)	Reach (cm)	Advise	Risk Value	Prediction
1	25	-	-	-	6	40	INL	0.2	NR
2	25	-	-	-	9	40	IML	0.6	LR
3	24	-	-	-	5	80	IML	0.6	LR
4	5	-	-	-	3	110	INL	0.9	MR
5	-	57	-	-	14	76	IML	2.8	HR
6	-	54	-	-	12	38	INL	0.54	LR
7	-	62	-	-	15	71	IML	2.5	HR
8		43			6	115	INL	0.4	LR
9	-	-	98	-	14	35	IML	1.4	MR
10	-	-	92	-	13	72	IML	2.5	HR
11	-	-	97	-	20	37	IML	1.6	MR
12	-	-	102	-	7	68	INL	0.4	LR
13	-	-		125	15	42	IML	2.4	HR
14	-	-		129	6	38	INL	1.5	MR
15	-	-		132	4	82	IML	2.2	HR
16	-	-		137	10	75	IML	1.5	MR

INL= Injury Not likely,IML = Injury most likely, MLH = Mid lower leg height, KH = Knuckle height, EH = Elbow height , SH = Shoulder height

3.3 Model performance. Sixteen scenarios and possible cases formulated by ergonomics professional are shown in Table 5 on each of the cases the height, arm reach and mass of load lifted by handlers were considered by the assessors using RAF in Figure 1. The linguistic predictions is as indicated. The same data were run with the model to generate risk values which were interpreted using Table 4 and the results are shown. The interpretations of the assessors and that of the model when compared shows that in 10 out of the 16 samples (63%) where assessor predicted “injury most likely” using RAF, the model also predicted one level of injury or the other in all the 10 cases. This represented 100% agreement using the two assessment tools. In the remaining 6 cases (37.5%) where assessor predictted “injury not likely” the model however predicted “low risk” in three of such cases (50%), “No risk” in one (25%) and “medium risk” in two (33.3%).

3.4 Statistics Analysis Tests. Spearman’s rank correlation coefficient of 0.99 was obtained when the RAF predictions were compared with the predictions of the model. This shows a strong strength of relationship between the output of the two assessment tools. With the SRC value of 0.85 obtained using SRC table at the confidence level of 0.01, there is greater than 99% chance that the relationship is significant. Hence there is no significant difference between the RAF injury suggestion and the model predictions.

3.5 Discussion. The study adopted fuzzy tools to evaluate risk connected with lifting and lowering objects based on three input variables; handler height (cm), weight of object (kg) and the handler arm reach (cm). One of the advantages derived with the use of this approach is that, fuzzy logic, unlike Boolean logic which does not provide the means to identify an intermediate value. Fuzzy logic handles the expression of vague concepts. For the fuzzy systems, truth values (fuzzy logic) or membership values (fuzzy sets) are in the range [0.0, 1.0], with 0.0 representing absolute falseness and 1.0 representing absolute truth [31]. The fuzzy rules of this format contains linguistic variables which is easier for users understanding result for users' easier comprehension of risks severity connected with the lifting attempt. For example stating ordinarily by the assessors that 'injury is most likely' in scenario 5 where a handler lift a 14kg weight from her 57cm knuckle height and her hand extended to 76 cm, may not be enough information needed for him to take necessary decision to avoid likely resulted injuries. However with the use of this model, additional information useful for taking right decision are provided. The model clearly mentioned that the lifting or lowering of such load will not only lead to injury, but that the risk involve is very high. The magnitude of the risk involved in this information provided by the model is quite easy to understand and help the handlers avoid vital injury that may be resulted.

The model provided good results comparable with the human assessors' opinions when selected scenarios were run in the model. In all the cases (100%) where assessor used RAF to predict either "No injury" or "Likely injury", the model interpretations also predicted one level of injury or the other only with additional information.

The fuzzy approach in this study considered inherent uncertainties of the membership classification process, such as in the classification of a handler reach with 45.5cm and another one with 46.1cm, which could be relegated both as NAM (Normal arm movement) and EAM (extended arm movement) at the same time. These arm movement (45.5 cm and 46.1 cm) simultaneously fit into the two membership functions but with different degree of memberships and interpretation of results.

A risk assessment model can be considered successful when it has the capacity at following human expert predictions and fulfilled the objectives for which it was developed. Hence success can be assigned to this model because it mimics the predictions of the human assessors with improved information that can prevent injuries and enhance safety and health of women handlers. The model can find its application among women in household chores and in workplaces where women are engaged in lifting or lowering tasks.

There are however a number of limitations that should be aware of for future efforts. One of which is the fact that posture of the individuals was not included within the analysis but forms a significant lifting risk assessment variable that could be covered. Future efforts may consider inclusion of such variable and the development of similar model for the menfolk.

4. Conclusion

In this study a fuzzy logic based model was adopted to evaluate the domestic Ergonomic hazards in lowering and lifting objects based on three risk factors of weight, height of load and the handler arm reach. The model provided a structure that gives vital information on the risk level attached to material handling at household chores where women are engaged in lifting-related tasks. The validation result indicated that the injury risk values and the linguistic interpretations provided by the model were confirmed the same with the ones provided by the human assessors (with the use of risk assessment filter) and with added improved information. Adopting this technique will reduce injury related medical bills and enhance safety and health of the womenfolk while handling materials in domestic duties.

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