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Ipaki, Bahram; Molenbroek, Johan F.M.; Merrikhpour, Zahra; Faregh, Seyed Ali

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Applying the quick exposure check in the workstation design process, physical and virtual prototype assessment

Bahram Ipaki[a,*], Johan F.M. Molenbroek[b], Zahra Merrikhpour[c] and Seyed Ali Faregh[a]
[a]*Faculty of Design, Tabriz Islamic Art University, Tabriz, Iran*
[b]*Faculty of Industrial Design Engineering, Delft University of Technology, Delft, Netherlands*
[c]*Industrial Design Department, Art and Architecture Faculty, Bu-Ali Sina University, Hamedan, Iran*

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Abstract.
BACKGROUND: The Quick Exposure Check (QEC) assesses four major body parts and engages users in assessing some physical interactions relevant to design in task analysis.
OBJECTIVE: In this paper, we investigated the application of QEC as the ergonomic intervention to detect pre-production ergonomic design faults in the apple sorting machine by applying physical and virtual prototyping for three different tasks analysis divided into two phases (Task 1: Apple harvesting and preparation for sorting; Task 2: Sorting control and separation of waste fruits; Task 3: Transfer of separated apples).
METHOD: First, the QEC questionnaire was administered while Iranian participants interacted with the machine to detect abnormal posture. Second, we redesigned a concept of the machine and assessed it with QEC by a focus group.
RESULTS: Before design, the high pressure in Task 1 is on the back (dynamic), shoulder/arm, and very high pressure in Task 2, and in Task 3 on the back (static), arm/shoulder/neck, making an uncomfortable situation for posture. After redesign, we observed decreased pressures on the back/shoulder/arm in Task 1 from high to medium, in Task 3 from very high to low, and also in Task 2, this was detectable decreasing from very high pressures on the back/shoulder/arm and the high pressures on the neck to medium.
CONCLUSION: Prototyping with QEC demonstrated that accurate redesigning of the machine with concentration on shifting from static tasks to dynamic or conversely, and ease of access by adjusting dimensions according to anthropometry and auxiliary products, could reduce musculoskeletal disorders.

Keywords: Equipment design, task analysis, ergonomic design, prototyping technique, human-machine interaction

1. Introduction

Ergonomic evaluation methods can identify a myriad of ergonomic problems in the product design process. Recently, there has been increased interest in the user-centered approach of ergonomics in evaluation via prototyping to improve the recognition of user needs [1]. The QEC method is one of several methods for assessing posture and musculoskeletal disorders in workplaces that typically requires a physical version of the product or machine for interaction tests [2, 3]. QEC is a method of assessing the posi-

*Address for correspondence: Bahram Ipaki, Faculty of Design, Tabriz Islamic Art University, Tabriz, Iran. E-mail: ipakdesign@gmail.com; ORCID: http://orcid.org/0000-0002-1687-3602.

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tion of the upper extremities confronting a device or a machine in static and dynamic tasks [4]. In this study, we intend to use the QEC method to evaluate the concept design of the sorter machine as a non-physical version and identify potential risks before developing the physical version. Prototyping is a method of representing an idea in order to evaluate or portray it as a product [5]. Prototyping allows us to reasonably comprehend the product's flaws, given that prototypes are not confined to physical models [6]. Prototypes are physical or virtual forms effectively operated to understand the user experience [7, 8]. As part of this process, we will need specialized tools to identify the QEC method and its application to non-physical prototype evaluation.

A physical model can assist for identifying product design problems during prototyping [9]. In contrast, physical prototypes of tools in design are known as physical prototyping, and some of them are of high fidelity, though high-fidelity features require extreme care and time to recreate the prototype, which, in turn, raises expenses. In certain circumstances, the product may have greater detail in computer simulation and finite components in the physical sample since some pieces are only utilized in mass production and cannot be inserted partly into the prototyping cycle [10]. Enhancing the degree of fidelity among prototypes will be able to prevent redundancy and errors. This topic refers to the contribution of prototypes to design data collection and information quality distribution, such as two- or three-dimensional models [11]. Prototyping is used in numerous phases of the design process between several properties, and the objectives are to represent ideas, monitor the quality of idea development, and identify and evaluate ideas [12, 13].

One of the major concerns in designing products or machines is the availability of users with varied BMIs and sizes when they use or interact with hardware [14]. Those methods of easing the complexity and accessibility of the equipment by identifying users' problems through their interactions with the product are highly effective techniques for detecting errors and providing solution suggestions. Research by Mahoney et al. verified that there are inadequacies in the approaches to designing a shared system of workstations [15]. Sometimes, a system is not optimized for single users, and multiple users with several demographic properties will operate the equipment. Therefore, different task situations should indeed be anticipated in the design process. However, depending on the type of activity, it is wise to select users with a suitable BMI [16]. The role of the concept in providing optimal products is evident to designers. Concept design is one of the essential design arguments that creators use to portray their initial ideas [17]. The recognition and design of the concept are two of the most important phases of development, with the design process for a product engineering design relying on the descriptive data of the idea [18]. When developing a product concept, we must be careful to estimate the amount of subsequent damage as accurately as possible. Thus, to decrease expenses, it is sometimes necessary to have an assessment before manufacturing a physical sample of the product. Choosing the proper concept to start the detailed design stage helps avoid future errors to a certain degree [19]. The concept design phase is distinct from detail design in the design process in that the designer must specify the overall configuration of the product [20]. There are several approaches to concept development in product design. However, adopting such approaches demands the capability of instruments and their suitable usage in certain scenarios [21]. Sometimes manufacturers have to analyze a product without visiting the physical prototype since concept evaluation is one of the phases of concept development [22]. One technique to effectively analyze structure-based products in the non-physical form of the idea is to apply a three-dimensional design in which designers use multiple computer-like displays to evaluate product photos [18, 23]. Thus, the correctness of each sample, depending on how much we simulate the elaborate virtual product, might be considered fidelity to the prototype. This simulation comprises a chain from the slightest fidelity to considerable fidelity, which reflects information including visual details and the user's experience [24–26].

2. Main problems and procedure

There exist several design challenges:

1- In ergonomic design processes, posture testing tools are either incomplete or absent while interacting with machines. In other words, posture assessment techniques are confined to 3D models and simulations before producing a physical sample. However, numerous ergonomic factors are not properly considered.
2- Designers are hunting for tools that describe the tasks of a massive part of the designs in the ideation stage to minimize mistakes and prevent

additional side expenditures. This issue is particularly problematic for small manufacturing enterprises and even start-ups.

3- Suppose a prototype of a product or a machine is designed to be assessed by the user's posture while working with it, and the equipment should be constructed such that there is not even a 1% probability of causing injury to the user. Therefore, it is advisable to execute testing on unreal samples to detect and disclose design faults using methodologies that complement each other.

This study consists of two phases; the first is how Iranian users interact with the sorter machine. In addition to detecting difficulties, problem-solving instructions are extracted in the results of this part, and in the second phase, the QEC is utilized for the ergonomic analysis of the final concept's sorting machine.

2.1. Phase-1

This phase has two purposes for optimizing the workplace conditions: 1-Evaluating the tasks and posture of workers by QEC to exhibit its performance as an ergonomic design tool during interaction with the sorter machine. 2-Establishing the design criteria and procedure of problem discovery and adopting the prototyping technique using QEC.

2.1.1. Case study

Using sorting machines in a small space encompasses both static and dynamic activities. A semi-automatic apple sorting machine in a small space is one of the types of equipment used in a workstation with several operators. The machine is one of the products that relies on the anthropometric features with which the operator interacts. Using anthropometric data for the structural design of some equipment in design projects is vital to increasing end-user comfort [27] for which the design of the sorter machine is no exception. The separation of high-quality export apples is a priority in the design of this machine. This product is utilized in small enterprises, while fruit sorting in large companies requires factories equipped with pneumatic systems. However, some individuals intend to expand their businesses in the gardens by promoting some of their exported fruits in unique packaging. For this reason, compact machines are necessary to reduce musculoskeletal disorders and other risks in the workplace. Various equipment has been designed and manufactured in Iran for this purpose. However, ergonomic aspects of workplace design, notably anthropometric topics, have not been observed owing to the non-interference of professional engineering designers.

2.1.2. Method

The study followed descriptive data to check the performance of the QEC throughout the design process for safe workstation idea selection. Figure 1 illustrates the conceptual model of the system. The data was evaluated after participants completed the QEC questionnaire. The data collected in the first step was transformed into a design transcript in the second phase.

2.1.3. Participants

The purpose of this section is to identify the different types of interactions and the number of tasks in which users interact with the sorting machine. The QEC survey was conducted on participants while they were working with the sorter machine in a garden. The total number of participants at work was 20, with two directly interacting with the sorter machine. The work system considered eight users cycling through their shifts to work with the sorter machine. Table 1 presents the BMI information of the participants.

2.1.4. Findings

2.1.4.1. Problem's identification. Figure 2 portrays users working with the apple sorter machine in a limited and confusing space. The length of the operation was 6 to 7 hours each day, and the users got a twenty-minute break every two hours while cooperating to manage the separation of the fruit. Unfortunately, in underdeveloped countries, non-compliance with product design concerns contributes to undesirable and irreversible effects for people. The weaknesses of the design systems in Fig. 2 are observable.

2.1.4.2. Task's analysis. **Task 1:** Apple harvesting and preparation for sorting: Sorting apples with sorter machines necessitates preparation and transport to the device before proceeding with the remaining procedures. At this stage, users initially adapt their posture to the environmental conditions; the necessity to exert excessive force generates strain on the user's back and knees, as well as the hands and shoulders, due to the machine's improper and non-anthropometric height.

Figure 2(a) shows the user hoisting the bucket and exerting pressure on the shoulder, wrist, and back.

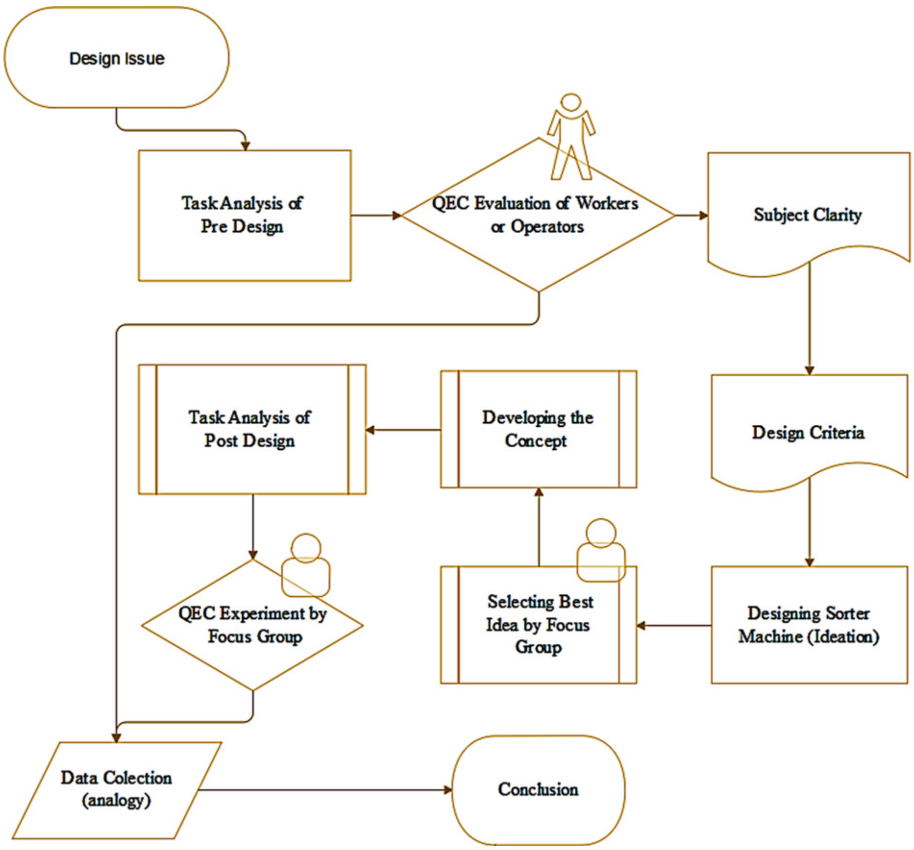

Fig. 1. Conceptual model of the design practice.

Table 1
Physical information of participants

Kind of activity	Gender	Weight	Age	Height [38]	BMI
Labor 1	Male	73	37	177	23.3 Normal weight
Labor 2	Male	68	33	169	23.8 Normal weight
Labor 3	Male	75	42	170	26.0 Overweight
Labor 4	Male	70	35	182	21.1 Normal weight
Operator 1	Female	68	30	165	25.0 Overweight
Operator 2	Female	72	32	172	24.3 Normal weight
Operator 3	Male	83	39	175	27.1 Overweight
Operator 4	Male	77	30	180	23.8 Normal weight

In addition, Fig. 2(b) and 2(c) show increased pressure (c). As a result of the hold-up hands, the user in Fig. 2(d) may experience temporary fatigue.

Task 2: Sorting control and separation of waste fruits. At this point, the user takes action to manage the fruits transported by the conveyor belt to prevent potential mistakes. Poor access of operators to fruit transfer surfaces due to non-observation of anthropometric points in the design, sharp edges that hinder users from moving adequately, and the likelihood of cuts and injuries to the elbows or forearms are some of the physical issues users experience at this stage.

Some of these disorders are depicted in Fig. 2. In sections (e) and (f) of Fig. 3, it is observed that a dangerous edge is utilized as forearm support. Besides, it is found that the operator performs lower sorting control on the machine desk in section (g).

Task 3: Transfer of separated apples: The third stage is the static procedure, in which the user must physically transport the apples from the machine surface to the bucket. According to observations, users may experience considerable musculoskeletal risks when they adopt high-risk postures to complete this step. Section (h) from Fig. 2 indicates a non-anthropometric factor that complicates the user's posture.

2.1.4.3. Posture's test. Based on anthropometric considerations and other design aspects, QEC was performed to uncover significant changes in the activities in two situations, including before and after design. These results will allow us to adjust the pos-

Fig. 2. Operator and labor problems.

ture and reduce the potential risks for the users. These needs are studied theoretically or practically. Table 2 summarizes the conclusions of disruption degree and risk prior to designing a customized machine based on on-site observations and a questionnaire.

2.2. Interpretation

2.2.1. Before ergonomic intervention

According to the QEC assessment, before the ergonomic intervention in Task 1, the pressure on

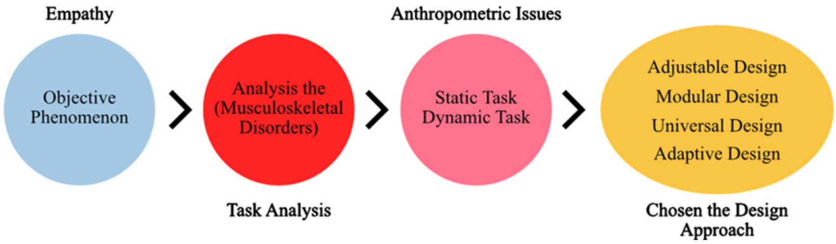

Fig. 3. Uniform of ergonomic problem to design language.

Table 2
QEC evaluation of workers (before design)

Task	Job title: Separate the apples by current sorting machine (before design) Task 1	Task 2	Task 3	Exposure legend
Total back exposure (static)		32	36	None
Total back exposure (dynamic)	32			Low
Total shoulder/arm exposure	40	46	42	Moderate
Total wrrist/hand exposure	22	28	26	High
Total neck exposure	8	14	12	Very High
Total driving exposure	4	9	4	
Total vibration exposure	1	1	1	
Total work pace exposure	4	4	9	
Total stress exposure	4	4	1	

the back, shoulder/arm exposure was high and the central pressures were on the back and shoulders, and the pressure on the hands and neck was moderate. Users also experienced a moderate range of stress on managing tasks, accuracy, and the stress of performing tasks. However, in Task 2 of the fruit control activity that is performed in a static position, the user faces very high pressure on the back, arms, and shoulders, as well as high pressure on the neck, and work is conducted with medium pressure on the hands and wrists, The precision of the work and stress are due to the difficulty of controlling the fruit due to poor access. In Task 3, there is a very high static pressure on the back, arms, and shoulders; a high pressure on the neck; and for the precision of work due to continuous rotation to transfer and throw fruit from the sorter machine surface to the ground; a medium pressure on the set of hands and wrists; and work conducting are seen to impose on the user interacting with the sorter machine. Also, vibration was determined to be ineffective throughout the activity process.

2.2.2. Design parameters

1. Observe the anthropometric protocol to correct posture
2. Creating more suitable access to the surfaces with the aid of a design
3. Reducing the direct musculoskeletal pressure in static activities
4. Accuracy in ease of use as well as safety in human-machine interaction
5. Lack of loss or damage to the fruit during separation

According to the results, the very high pressure in all three tasks is on the back, arm, and shoulder. The neck posture is especially troublesome in tasks 2 and 3. Two significant factors impacting safety and musculoskeletal disorders are 1-access limitation 2-how to design details. The amount of access is contributed to anthropometric data management, and the design of the details is related to the quality of interaction and usability, which in the research sample had multiple challenges. In general, the process of reaching the desired approach to addressing the issue could be represented as follows:

1- Adjustable design: With this approach's support, the product's structure and body may be designed in an adjustable anthropometric range so that more users with wide-ranging anthropometric dimensions can customize the product attributes according to body size.

2- Modular design: With the aid of this method, a variable arrangement of components could be offered to the user to allow him to reconfigure his physical state to the position of executing the task.
3- Universal design: In this approach, the anthropometric average of the studied users (considering their geographical location and morphological structure) should be extracted according to different percentiles to be considered as anthropometric data in evaluation and design so that it ultimately leads to an equitable use of the desired product for all users.
4- Adaptive design: According to this approach, due consideration should be given to auxiliary facilities and adjacent products so that if for any reason the product is inconsistent with the anthropometric data of users, they could utilize nearby products to compensate for deficiencies and gaps. For instance, if a table is not height adjustable, it is feasible to optimize the use of the table by providing a chair with the option to adjust the height. Figure 3 presents the conceptual model for choosing the design approach according to the stages of understanding the anthropometric problems.

2.3. Conceptualization of the QEC in problem prototyping

It is feasible to examine the workstation segment where users interact with equipment using the QEC approach. The tasks need to be separated into static and dynamic categories and analyzed independently, and this procedure has been done in the same predictable way. Since the accurate identification of problems and their proper evaluation is one of the fundamental factors in design, it is simpler to attain the optimum model if the ergonomic problems of a product are accurately identified for development or redesign in the subsequent steps. For this purpose, users' pain and physical discomfort could be assessed independently and clearly by utilizing the QEC tool to rapidly diagnose the issue. In this method, each segment is organized and does not need to categorize and classify the ergonomic design problems independently.

2.4. Design's prototyping

Indeed, the power of event simulation affects the accuracy of the evaluation results. However, it is complex to build physical samples of the product and machinery and evaluate them sequentially due to their high costs and potential safety hazards. We continue to emphasize that focusing on testing non-physical samples is very effective in design and production. In this regard, it is beneficial to study prototyping tools' feasibility, effectiveness, and applicability, as well as risk assessment tools in human factors. The effectiveness of these tools can be different in combined or separate modes, and this issue needs further investigation. The goal of using design tools in the design process is to reduce errors and achieve a more efficient design, with a priority on inexpensive tools that can accurately diagnose design problems in a short period of time. That is not a big claim because their use does not disrupt the design process. Some design requirements were not met. Hence, the final product is a bit distant from the optimal design. In this situation, what methods and tools are appropriate to identify anthropometric problems in evaluating raw ideas and image prototypes in the process? In any case, at the end of the physical sample design process, the user must be tested, and we have no claim to remove the evaluation of the physical version of the product. However, it is possible to save money and time by identifying and fixing some design bugs in the early stages. Using QEC to test early design ideas can play an important role. Figure 4 depicts a process and some prototyping tools for working with machines or going through hypothetical scenarios at a workstation. Pay attention to two factors that are critical for detecting prototype approaches.
1- Reconfigurability: It indicates the flexibility of the method adopted in considerable or diminutive changes. We will presumably come up with fresh ideas by making changes to the idea of designing a workstation or desiring to modify previous ideas, and the reconfiguration level provides the necessary speed for that.
2- Fidelity: The level of fidelity to separately prototype varies. Any prototype that can accurately reveal the details of an idea is more reliable. However, the speed of generating ideas in it may be due to the low level of complexity.

Finally, a description of the main criteria proposes for the practical design of the prototype, and an application of QEC in the concept presentation stage are offered. In the investigation's second stage, a design was made to validate it. Workstation prototyping approaches have frequently gotten less attention. With an equipment design at a workstation, this practice detects the defective parameters before constructing a physical prototype and, with the assistance of a multi-phase study, exhibits the advantages of applying a dedicated process. The current

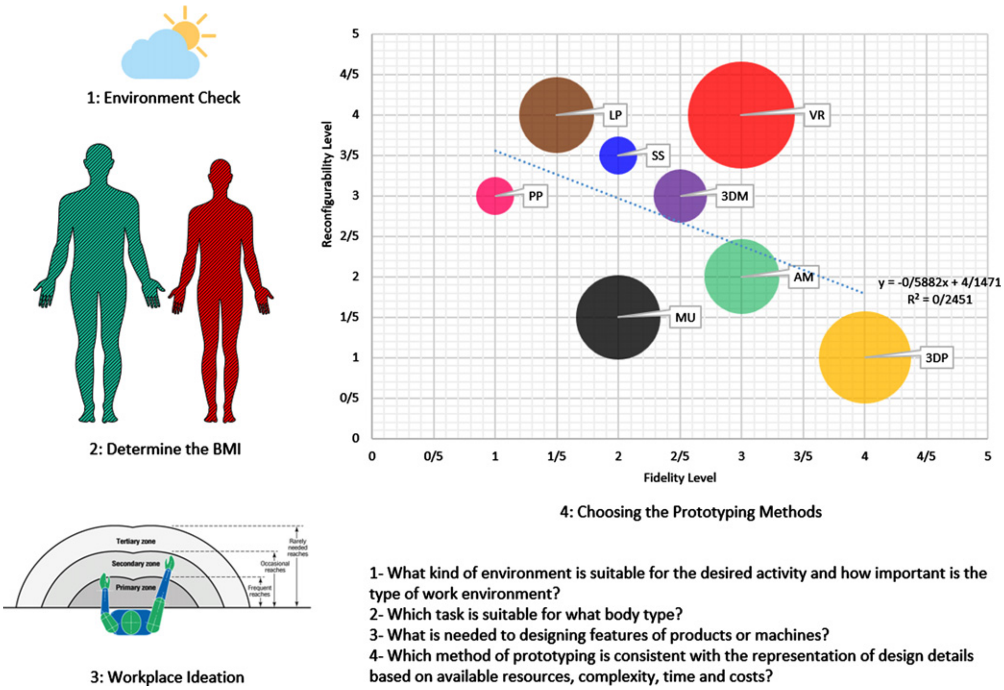

Fig. 4. A proposal for the involved process in workstation prototyping. PP: Paper Prototype, LP: LEGO Prototype, SS: Scenario Sketching, 3DM: 3- Dimension Modeling, VR: Virtual Reality, MU: Mock-Up, AM: Animation Modeling, 3DP: 3-Dimension Printing.

practice reveals that adopting ergonomic assessment methodologies in the design or concept development phase would be less expensive. Also, adopting QEC tools in assessment contributes to detecting specific design gaps, which enables us to develop the optimized solution rapidly. Because QEC is a quick MSDs (musculoskeletal disorders) problem-finding tool, this supposition could be confirmed as a design case in the following related procedure. Therefore, by developing previous protocols for ergonomic assessment approaches in product design, they can be introduced as crucial problem-finding tools for designers.

2.5. Phase-2

In Phase 2, we follow the cross-validation of the performance of QEC after generating the concept in re-evaluation via integrated prototyping. The work situation for concept design was described to the focus group after sketching, and then the group argued the concerns. Then, the two modes, pre-design, and post-design were compared. The findings of each questionnaire were inserted into the QEC checklist on average in the pre-design and post-design stages and analyzed using SPSS 21. This practice has three purposes: 1-Making a visual prototype of the apple sorting machine concepts according to the specified criteria from part (A) and task scenario sketching. 2-Qualitative effectiveness of QEC in assessing the sorting machine design. 3-Presenting the checklist of all elements of design for developing the sorting machine.

2.5.1. Method

2.5.1.1. Expert panels. To assess the status of users after the design of the sorter machine, we created a focus group of two faculty members in the field of industrial design, two faculty members from the ergonomics group, five senior industrial design experts, and one gardener who had any experience using the sorter machine. The focus group was engaged in assessing new concepts and designs. Due to the complexities of machinery design and production, as well as their high costs, in this practice, cheap and relatively accurate methods were used to identify the fundamental problems, and the results were evaluated by a focus group due to the limitations of evaluating machine concepts designed in the workstation by users. The implementation of sustainable approaches in all phases of the design of this pricey equipment is of significant relevance [28]. In focus group meetings, topics are conveyed to the group members, and it is possible to discuss complex issues according to the group's expertise [29].

2.5.1.2. Facilitator. A facilitator was responsible for describing the design configurations and leading the participants and the group. The facilitator presents the specifics of the challenges and ideas and advises the participants if there are any uncertainties in the testing process.

2.5.1.3. Modes of prototyping. Initially, two-dimensional sketching was utilized to generate ideas. A two-dimensional sketch is a low-fidelity prototype that can be reconfigured, and the idea generation speed is relatively high. In this prototyping technique, each component of the functions and tasks on the device is recognized to understand the operation and the process of product operation. After performing an initial assessment of the ideas, we developed 3D models, known as "middle-fidelity prototypes," to better represent the product and extract an industrial map alongside it. Scenario sketching and the development of 3D image renderings enable the expert team to evoke users' postures.

2.5.2. Design process

2.5.2.1. Idea generation. Figure 5 depicts some sketches as part of our effort to enhance the ergonomic circumstances according to the design requirements. The experts' comments were implemented after generating various scenarios and presenting them to the focus group. Sketch plans for the scenario, and the potential to analyze should have two aspects: planning and objectivity [30]. The sketching scenario illustrates the user's journey in front of the machine, which is shown in part in the figures below. The final four concepts are presented below. Concept A: Indicated a drawing of the sorter concept designed by the assembly part that designed two non-detachable funnel trays in the initial and last parts of the machine. Also, there are two drawers for sorting different apple sizes. Concept B: A modular design sketch of a sorter machine that enables easy transfer by car. Different parts of this concept device could be detachable and foldable. Alongside, there are two drawers, Concept A and Concept B, and due to the improved accessibility, operator posture is better. Concept C: This is similar to concept A. The difference is that the funnel tray increases height in the initial part of the machine, and sections from different apples use cavity circlet cylinders instead of cylinders. Concept D: This design is very different from the three previous concepts. Here, the drawers are not removable. In addition, the sorting method in this concept will be different, with users having to collect apples from non-removable drawers one at a time.

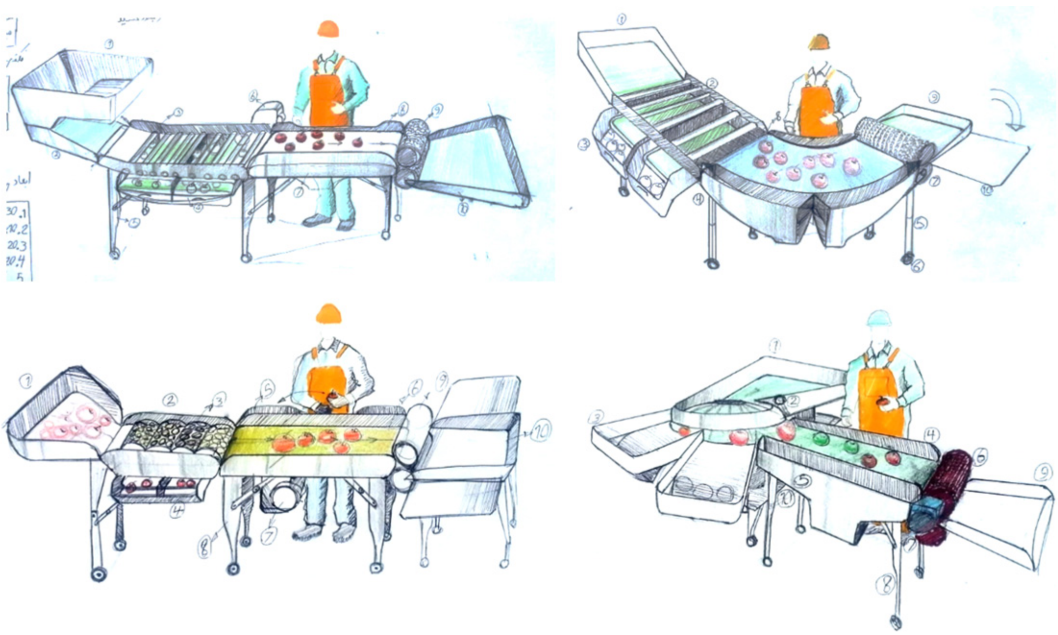

Fig. 5. Scenario idea sketching.

2.5.2.2. Idea evaluation. Given the lack of generality of the present outcomes in this phase, the designer must analyze the developed ideas according to the design criteria. Four final concepts are presented to enhance the design of the apple sorter machine, one of which should be selected as the top product. In this technique, the design requirements were first compared using the fuzzy method. Their numerical weight is listed in Table 3. Then the concepts were compared by criterion weight. According to the data collected from the consensus of the focus group, Concept B was eventually selected as the best design, as shown in Table 4. The fuzzy method is still one of the most frequently used tools for assessing product ideas [31] used in this study.

2.5.2.3. Idea presentation. The preferred idea was developed into a 3D design using Rhino software and rendered with KeyShot software to make the details more transparent for the focus group. Providing 3D models for workstation assessment is an effective and relatively rapid option [32]. Figure 6 presents an overview of the final concept.

2.5.2.4. Task solutions. **Task 1:** Resulting in a shift in the user's posture and the observation of anthropometric points in the design, the position of the back, shoulders, and arms has experienced considerable adjustments. Lifting the fruit basket and pouring it into the tub, owing to its perfect height, minimizes the pressure on the back, shoulders, and arms. Placing the tub in a sloping position leads to rapidly pushing fruit to the rails without hand intervention. The maximum height of the tub is 91.7 cm, while the minimum height is 77 cm. In this approach, the position of the user's body will be considerably better than the previous position.

Task 2: To effectively regulate fruits, the work surface is designed for the operator according to his anthropometry and his access, with a maximum radius of 50 cm. Figure 7 portrays the user's status as intended for work in such a manner that the user sits in a unique chair and accompanies the activity. The user should also have a BMI appropriate for the position of the settlement in order for his height and weight control to function properly. According to the studies, this condition was dictated by the machine's new design.

Task 3: To reduce extra force on the user in the new design, an effort was made to transform the static process into a dynamic process by adding distinctive drawers with ergonomic handles and detachability. In this mechanism, instead of discarding the fruit off the surface of the sorter machine, the fruits are moved straight to the designed drawers, and the large

Table 3
Design criteria, preliminary focus group decisions

Fuzzy logic parameters-evaluation in case study (apple sorting machine)	Accessibility	Ease of transport	Ease of use	Health	Safety	Reduce errors	Aesthetics	Pleasure of work	$\sum$
Accessibility	1	1	1	1	0	1	1	1	7/8 = 0.875
Ease of transport	0	1	1	0	0	1	1	1	5/8 = 0.625
Ease of use	1	0	1	1	0	1	1	1	6/8 = 0.75
Health	1	1	1	1	1	1	1	1	8/8 = 1
Safety	1	1	1	1	1	1	1	1	8/8 = 1
Reduce errors	0	1	1	1	1	1	1	1	7/8 = 0.875
Aesthetics	0	0	1	0	0	1	1	1	4/8 = 0.5
Pleasure of work	1	1	1	0	0	0	1	1	5/8 = 0.625

Table 4
Concept selection by focus group

Parameters-Likert scale: Too weak (1) Excellent (5)	Concept A	Concept B	Concept C	Concept D
Accessibility	2×0.875	5×0.875	3×0.875	4×0.875
Ease of transport	2×0.625	5×0.625	2×0.625	4×0.625
Ease of use	3×0.75	3×0.75	3×0.75	2×0.75
Health	2×1	4×1	2×1	3×1
Safety	5×1	5×1	5×1	3×1
Reducing errors	2×0.875	4×0.875	3×0.875	4×0.875
Aesthetics	4×0.5	5×0.5	3×0.5	2×0.5
Pleasure of work	2×0.625	4×0.625	2×0.625	4×0.625
$\sum$	17.25	**31.15**	18.5	20.5

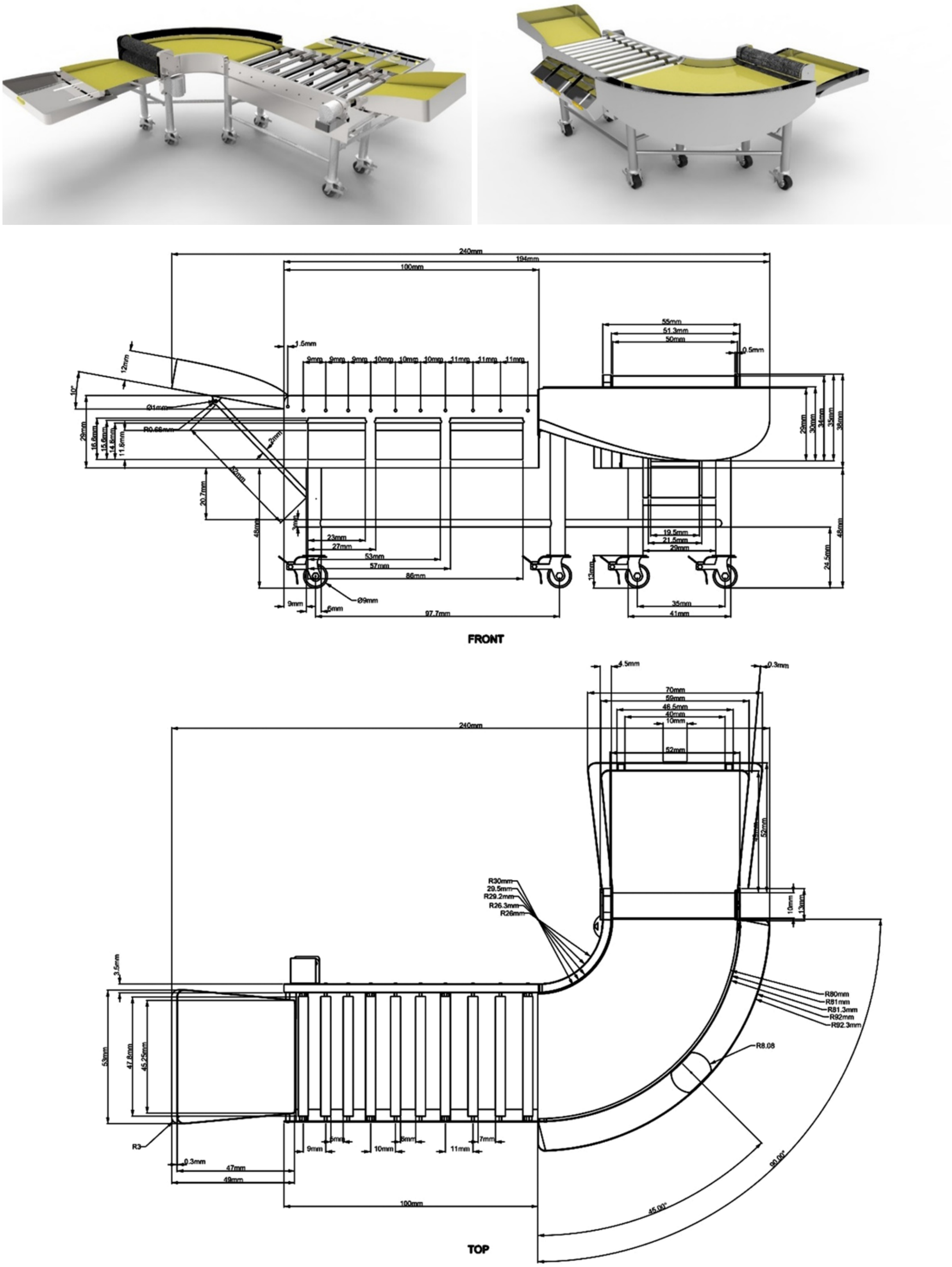

Fig. 6. The developed image of the concept, rendering of the machine with technical drawing.

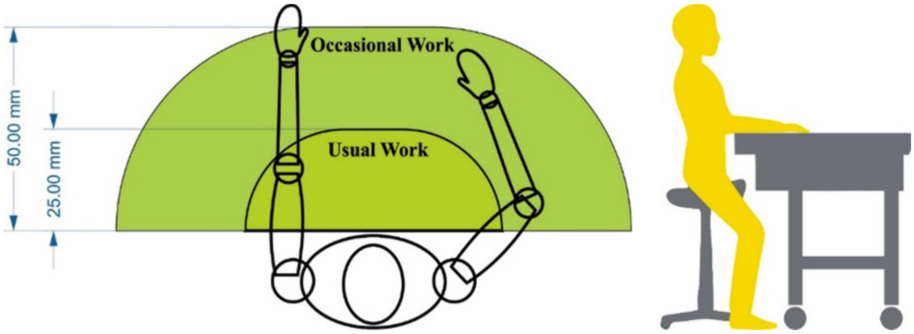

Fig. 7. Applied access status in design. Proposed status of the operator according to the design.

Table 5
QEC evaluation by experts-panel in focus group (after design)

Job title: Separate the apples by designed sorting machine (after design)				Exposure legend
Task	Task 1	Task 2	Task 3	
Total back exposure (static)		18		None
Total back exposure (dynamic)	28		20	Low
Total shoulder/arm exposure	28	26	16	Moderate
Total wrist/hand exposure	22	16	20	High
Total neck exposure	8	8	4	Very High
Total driving exposure	4	4	9	
Total vibration exposure	1	1	1	
Total work pace exposure	4	9	4	
Total stress exposure	4	1	1	

and exported fruits reach the last drawer. There is also a removable side slider embedded under the end drawer. At this stage, switching from a static activity to a dynamic one will counterbalance the pressure on the user's back.

2.5.3. *Hypothetical outcomes*

2.5.3.1. Posture test. Based on the design, the findings are inserted into Table 5. To achieve the comparative results, we applied the scenario sketching of the final designed machine concept to the focus group and put a hypothetical user in an interaction with the concept and assessed it.

2.5.3.2. After ergonomic intervention. Changes made via anthropometric design in Task 1 decreased the pressure on the back and arms/shoulders from high to medium. In Task 2, the very high pressures on the back, arms, and shoulders and the high pressures on the neck were decreased to moderate. However, owing to the reduction in human resources to boost profitability and productivity, the number of operators was reduced from two to one, for which the speed and precision of work must increase. Therefore, we detect an increase in risk at a medium to extreme exposure pace. Also, owing to the suitable structure of the sorter machine and the unique determination of the fruit stands, the tension has been minimized to a short range. In Task 3, the risk level in the back, shoulders, arms, wrists, and neck was decreased to a short range by transforming static activity into a dynamic condition. However, driving exposure exposes a significant risk because work is taken out of the static mode, which the user has to rest to control. Pace exposure level has been decreased from high to medium owing to the ergonomic design of the drawers and the proper access level. Overall, the rate of reduction of musculoskeletal disorders with enhanced design is summarized in Table 6. The QEC scores, overall, indicate a 37.33% improvement.

3. Discussion

3.1. *Design properties*

Multidimensional examination of a product's ergonomic status requires using assorted tools and

Table 6
Final results of analogy, E (%)=X / Xmax × 100

Task: Percentage (%) QEC results	Comparing before and after design in improving the MSDs Task 1	Task 2	Task 3	Total
Total back exposure, current	57.14	57.14	64.28	%59.52
Total back exposure, designed	50	32.14	35.71	%38.28
Total shoulder/arm exposure, current	71.42	82.14	75	%76.18
Total shoulder/arm exposure, designed	50	46.42	28.57	%41.66
Total wrist/hand exposure, current	47.82	60.86	56.52	%55.06
Total wrist/hand exposure, designed	47.82	34.78	43.47	%42.02
Total neck exposure, current	44.44	77.77	66.66	%62.95
Total neck exposure, designed	44.44	44.44	22.22	%37.03
Total current – Total designed ÷ Total current × 100 = total of the improvement	%7.73	%43.22	%50.48	%37.33

Table 7
Checklist of concept design satisfactory, direct feedback of focus group

Criteria	Situation	Reasons
Apple sorting	Satisfaction	Apple separation is compatible with the current concept in terms of sizing. Therefore, four drawers are considered.
Waste sorting of big apple	Satisfaction	Separating high quality apples from waste apples is possible.
Small apple waste sorting	Sacrifice	Small waste apples are placed in the drawer with other small apples (due to the availability of fresh products, this does not happen).
Storage	Satisfaction	Apples are stored at specific sites.
Accuracy	Dissatisfaction	It is relatively acceptable, but it should be tested after the physical sample for the relationship between accuracy and performance.
Speed	Satisfaction	It is possible to adjust the speed by choosing the motor power.
Handling	Satisfaction	The classification of work procedures in the configuration presented in the structure is based on the handling of tasks by users.
Stability	Satisfaction	Due to the number of stands embedded in the structure with brake-built wheels, it is stable.
User interface	Dissatisfaction	Regarding electronic processes, items such as speed adjustment, on and off, etc. need to study interactive design and graphic communication.
Wayfinding	Satisfaction	The user journey is transparent in doing the task.
Repairable	Dissatisfaction	In this concept, the repair capacity is limited to some parts, and the design must be developed to promote the capacity.
Transferability	Satisfaction	Due to assembly, fragmentation and wheeled elements, it is easy to transfer the system.
Ergonomic sound	Dissatisfaction	Examining the motor noise is needed to check the prototype.
Electronic system	Dissatisfaction	The electronic system cannot be evaluated yet.
Material	Dissatisfaction	The performance of materials in the proposed machine should be monitored in the physical sample.
Permanency	Dissatisfaction	Machine durability is determined after the product is used and the elements are scrutinized.
Ease of performing tasks	Satisfaction	The procedures are clear.
Aesthetics	Satisfaction	Appearance features comply with the environment.
Intelligible	Satisfaction	Due to the small number of tasks, the process is reasonable. Three main tasks are defined for this machine.
Controlling	Satisfaction	Users have control over the performance of the machine and their tasks.
Learnability	Satisfaction	Users learn how to handle the task, and it is not complex to work with the system.
Consistency	Dissatisfaction	A physical sample is needed to test the integrity of elements.
Compatibility	Dissatisfaction	The compatibility of structural elements with each other is not confirmed.
Severability	Satisfaction	Most connections are temporary, so they can be displaced easily.
Hygiene	Satisfaction	The machine and its elements are washable, and the drawers are too.
Structure simplicity	Sacrifice	The whole structure, especially the quadrant section and big apple sweeping, is complex, and manufacturing costs become high.
Ease of manufacturing	Dissatisfaction	More scrutiny is needed regarding the workshop and laboratory equipment, and a physical sample must be made.
Teamwork	Satisfaction	The group knows their tasks well, and the tasks do not overlap.

Table 8
Functionality of QEC in raw design idea assessment

Issue	Solutions	Reasons
Posture	Yes	Regarding the anthropometry data in dimension and size, the concept is evaluated.
Accessibility	Yes	The structural form of concept is evaluated regarding the anthropometry data in various dimensions and sizes.
Adaptability	Maybe	Only in terms of users' anthropometry data and its compatibility with sorter machine structure.
Usability	No	The applicability of the system must be checked more specifically.
Desirability	No	It requires cognitive data.
Vibration	No	Physical samples are needed (in the concept of the sorter machine, it was impossible to make an evaluation).
Space saving	Yes	It is possible to evaluate the system regarding the compatibility of concept structural dimensions with the environment.
Modularity	Yes	The structurally fragmented parts can be evaluated.
Safety	Maybe	It is limited to some parts related to anthropometry data.
Ease of transport	Yes	Pushing, pulling and lifting the concept in the scenario sketches is simulated and can be evaluated.

techniques [33]. Consequently, it is inevitable that the additional requirements of the designed sorter machine have not been studied in the present investigation. However, the recently proposed idea may help enhance the posture situation (Table 7).

The leading operator is accountable for the complete control of the fruit. In this method, if a minor or waste fruit is among the excellent fruits, he dumps it into the tub opposite. Sharp edges in the design have been controlled and eliminated according to the zones where the user may be injured. The final product designed by observing anthropometric tips has led to improved access and a significant reduction in musculoskeletal injuries, so that in the designed position, the rate of bending of operators' backs has been reduced to less than 20 degrees, and by reducing the number of repetitive activities in each part of the task, the level of productivity has increased. In order to make transportation of the gadget by vehicle more accessible, it has been developed with portable proportions suitable for a van, the tiny size of which results in a decrease in its ultimate weight compared to the previous variants. The drawers utilized are intended to make it easy to remove the fruit, with cushions that prevent damage to the apples. Also, the designed sorter machine can separate different sized fruits and round melons. Oranges and tomatoes or onions might be incorporated into this design.

3.2. *Design checklist*

Occasionally, some factors may be sacrificed to achieve precise goals in product design [27]. Consequently, it is inevitable that the additional requirements of the designed sorter machine have not been studied in the present investigation (Table 8). However, the recently proposed idea may help enhance the posture situation.

3.3. *Novelty and conceptualization of the QEC in concept design evaluation*

The unifying feature of the present study is similar to the findings of Bligård et al., who utilized focus groups to assess simulated scenarios in the form of sketches and 3D files. They concluded that regular members could not assess the sketching scenario at the workstations and that the participants discussing the issue should have acquired the requisite training [32].

Also, the results of this study are similar to those of Tiwari et al. [22] in terms of the influence of design pictures on designers' understanding of inaccurate and ambiguous content in the original design. It was conceivable to generate redundancy by introducing extra elements to resolve the problem. Therefore, the development of the designed sorter machine must be done individually. Redundancy may be a nuisance in a system. For example, in the previous sorter machine, we noticed various procedures for humans. Designing extra places for components in the previous sorter machine structure required an operator. The risks of the workstation were reduced by automating these procedures and altering the role of users in the final design. Table 8 further emphasizes the function of the QEC for anthropometric concept redundancy analysis.

The most notable novelty of the present study is its difference in evaluating additional parameters and body parts compared to earlier works in the area of digital human modeling (DHM). The most notable and extensively used equivalent method is the use of CATIA software associated with RULA assessment.

Nikhilkumar et al. [34] conducted a study on blacksmith posture using RULA in CATIA and discovered that ergonomic adjustments reduced the amount of risk and issues. However, in certain other circumstances, such as the degree of stress, vibration, and control, it cannot be assessed using this system, and this is a major problem that indicates the weakness of this assessment method. DHM has evolved as a significant technology in the simulation of work settings to provide improved solutions for ergonomic design and workstations. Human digital mannequins are incorporated into software that may be readily adjusted to examine workstation design, discomfort, and associated injuries resulting in musculoskeletal disorders. Workers in small businesses frequently complain about pain and discomfort while performing their duties. If not treated in the early stages, it may lead to the continued development of work-related musculoskeletal disorders and other major difficulties, such as low back pain (LBP), which impact the productivity and efficiency of workers [34].

Some recent related studies, such as those by Jadhav et al., Rathore et al., and Gajbhiye et al., that performed prototype and simulation for ergonomic assessment, were limited to posture evaluation with RULA or static activities, and they emphasized the development of some tools, devices, or equipment [35–37]. Also, their research was focused on correcting posture. However, this is not enough, and machines are effective in forcing postures. In this study, the approach is more holistic, such that we could modify the user's posture with the assistance of some upgrades in the machine, concentrating on the design and not simply behavioral or clinical prescriptions.

The difference between this study and Mahoney et al.'s research is that instead of homogenizing the demographic domain to regulate the anthropometry of various operators, we reduced the number of operators based on structural design and task modifications. That would not have been achievable without the QEC method since the sections that required ergonomic intervention were predicated on the availability of other users and operators. In the study of Wanberg et al., merely because the ergonomic data were not adequately analyzed at the concept design stage, the physical product version was not aimed for the final test [27].

We determined that utilizing the QEC assessment process might lead to an ideal workstation product concept by providing fresh viewpoints for the designer. However, the function of the focus group should not be disregarded. Figure 8 portrays the conceptual model of the present study's position in the design process's conceptual space. Thus, if we have a non-physical concept with job scenario sketches, we can evaluate the main idea by participating in the presence of experts and forming a focus group, and by recognizing its shortcomings and eliminating problems, we can turn it into an optimal concept to reduce the risk of redundant design. The QEC performance depends on the design and details of the workstation.

3.4. Limitations

One of the most critical design issues is hypothesizing. Hypotheses generate design ideas that may be translated into valuable and optimal concepts before construction and production to avoid the design and construction of redundant and destructive instances. In this study, too, having examined the ergonomic condition of the employees, everything was done semi-empirically to represent a particular procedure for the audience, arguably the present study's significant shortcoming. For example, in the application of QEC in certain circumstances, despite our information about the user's unsuitable posture in interacting with the device, the average score provided by the expert board based on the assessment table is considered the final score. The proposed conceptual design is still a clear departure from the wholly optimized model, and this approach has merely highlighted the limitations of the conceptual design that are extremely important in the ergonomic design process.

Also, the assessment speed with this approach is a little low. Because everything is done manually or without artificial intelligence (AI) techniques. Alternatively, if this is done with the assistance of AI, it could generate output more rapidly and does not rely on some expertise.

3.5. Future studies

It is recommended that, in future research, some algorithms to simulate this process in software be supplied so that faults might potentially be prevented without the necessity for a group of experts or data from users. For example, simulating the RULA assessment inside CATIA software is comparable. For the continuation of this study, artificial

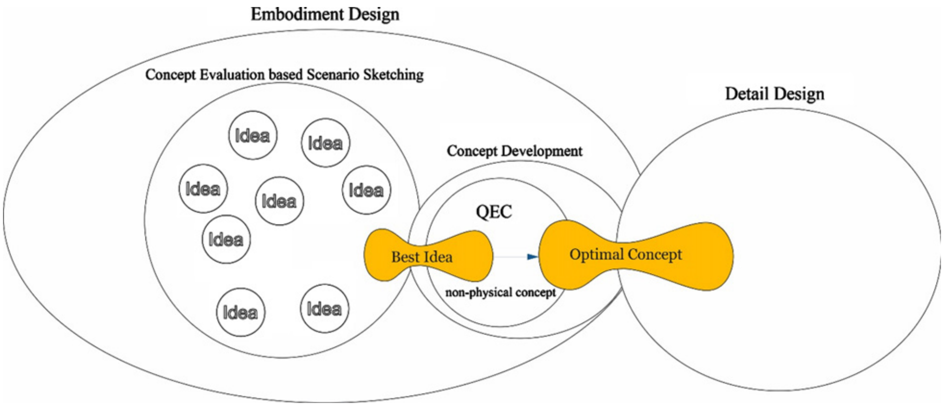

Fig. 8. QEC status in the concept development stage in conceptual model of design process.

intelligence research with access to users' anthropometric data as well as the process of performing each task through the device's dimensions is useful. This enhances the assessment's efficiency and accuracy in the safe design of equipment.

3.6. Relevance to industry

A physical prototype is often expensive. Therefore, it is optimum to detect the design faults before the prototyping phase in the ergonomic design process. Because specific items may not necessarily need a physical prototype for assessment, this claim may alter depending on the product's structure. Focus groups can use QEC to evaluate posture in the non-physical prototype of the concept design process when the product family has anthropometry-based structures, such as some workstation machinery, furniture design, or some medical equipment like a patient transfer bed, etc. where accessibility plays a critical role in safety and performance.

4. Conclusion

This investigation emphasized the indisputable importance of anthropometry, the task process, and the workstation setting in prototyping. The study's outcome suggests that adopting the QEC assessment approach in non-physical concept (sketch scenarios, computer 3D simulations) assessment of the ergonomic design process, especially anthropometric products, may uniquely discover pre-production design faults. Combining the presentation of computer models with sketches of activity scenarios creates a prototype, making it possible to comprehend it with the assistance of the QEC in a restricted form and perform assessments without producing a physical sample. However, depending on the type of user, the concept style contributes to making it operational. These concepts have complex aspects in that they require comprehending their non-physical samples accurately and virtually measuring human interaction with the machine. However, for a comprehensive approach to resolving this problem, the relevance of focus group sessions is undeniable. Using hybrid approaches may generally become an economical tool for designers and developers of optimal designs and concepts for manufacturing. Concept design should be frequently considered to analyze product and equipment errors further. Designers should consider that the QEC may be an ideal hypothetical approach for assessing an idea at the concept design stage, mainly where anthropometry in the product significantly decreases the risk of ergonomic disorders. This study demonstrated that concepts and ideas could be semi-empirically evaluated with the QEC and that potential limitations could be resolved during the concept development phase, avoiding the use of additional project resources. Because the purpose of the concept design phase is to represent the idea for better assessment, decrease design failure, and avoid high costs in product manufacture, Using the aforementioned ergonomic assessment approach at the concept design stage is advised for designers, researchers, research and development groups, and manufacturing enterprises.

Ethical approval

Not applicable.

Informed consent

The participants acknowledged and consented that their involvement in the study is voluntary, and they could resign at any phase. There were no risks or hazards in conducting this research with participants. This investigation is based on the Declaration of Helsinki and the ethical aspects of human research.

Conflict of interest

There is no conflict of interest regarding this paper.

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