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Worker-Centered Design for Working Area in the Electronic Industry

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Objective: This research provides a guideline for working area design in the electronic industry, considering gender differences of physical characteristics.

Background: Co-work in the electronic industry requires workers of various physical properties to work cohesively in the conveyor line for mass production. This stresses the need for a worker-centered design of the workplace convenient for all the workers.

Method: In this research, the 6th Size Korea (National Anthropometric Survey in Korea) report is referred to obtain the design measurements according to age and gender varieties. This information is used to provide the working area guideline concerning conveyor line workers of both genders aged 20 to 40.

Results: Physical properties of workers and workplace design principles were obtained for application in the assembly, inspection, and material handling process in the electronic industry.

Conclusion: Applying ergonomic design principles can provide safe and comfortable workplace for both genders.

Application: This research can be fundamentally used in designing worker-centered workplaces.

Keywords: Conveyor line, Working area, Electronic industry, Worker-Centered design

1. Introduction

Interest in worker-centered design recently increases under the paradigm that people with various physical characteristics can easily and comfortably use workplace together. Since worker-centered design is reported to make contributions to worker's safety and productivity improvement in a variety of fields, its importance is huge (Jeong and Kim, 2011; Pyo and Jeong, 2007).

Concerning the conveyor line production type, which is a production mode of electronic products, because workers with different physical conditions should work on one conveyor line together, design philosophy providing workplace, where all workers do not feel inconveniences, is regarded as very important. In the traditional linear conveyor line, the type like cell production mode is recently activated from the productivity improvement and workers' physical activity diversification perspectives.

The cell production mode is a production type, in which one worker or several workers in charge of multi-processes in the workspace called "cell" assemble parts. Because, one worker of several workers can participate in any type of processes, workplace area design considering workers with various characteristics is needed.

To design working area suitable for workers' characteristics, it is desirable to design by reflecting anthropometric measurements by gender and age of the workers participating in work. Although, studies using anthropometric measurements for the design of electronics, furniture and clothes are activated, not many studies applying the measurements to workplace design are found (Jeong and Park, 1990; Gouvali and Boudolos, 2006; Jung et al., 2007; Kang and Jung, 2009; Jung et al., 2009; Daruis et al., 2011). European EN 894, the U.S. NFPA 79 and MIL-STD-1472 and international standard, ISO 9241, are utilized as the guidelines for working area design. Especially, EN 60204-1 and SEMI S8-0701 are used in the electronic or semiconductor industries. Some Korean semiconductor manufacturers set and use working area-related design standards as internal standards, and even some manufacturers recommend their partner firms (contractors) to comply with the working area design standards. In hazard factors survey conducted in every 3 years according to the Industrial Health and Safety Act, guidelines for working area design taking into account workers' physical sizes for work safety and productivity improvement are greatly required, as work process is intended to be improved.

The purpose of this research is to offer a guideline for design of working area, based on worker-centered design principles concerning design factors to consider in the representative processes of electronic industry's conveyor line. In a workplace, where both male and female workers having the working area of different characteristics need to work together, this research aims to offer guidelines to consider working area, in which both male and female workers can easily, comfortably and safely work together.

2. Method

The characteristics of electronic products are represented as both small and large sized-products. The products like camera, navigation and MP3 show a small-size trend, while TVs show a large size trend. In the production line producing small-sized products, relatively no big problems arise in designing working area, since work is conducted within worker's normal working area or maximum working area. However, bigger products than worker's working area can be produced in a large-sized electronic product production line. For this reason, worker-centered design philosophy is needed in reflection of worker's characteristics by gender and age.

This research intends to present actual working area design measurements in consideration of worker characteristics and product characteristics in the electronic industry. In the electronics industry, female workers account for about 80~90% of workforce, and their age bracket is mostly 20s. However, male workers' age brackets span from 20s to 40s. This research actually limits research scope to designing working area targeting male and female workers in their 20~40s in the large-sized electronics production line workplace. This research aims to draw working area design factors by production line process, and offer specific design principles and design measurements on working area design. For the design measurements required for working area design, this research uses anthropometric data by age and gender drawn in the 6th Size Korea (National Anthropometric Survey in Korea) report conducted in 2010.

General electronic industry's manufacturing processes can be classified into assembly process, inspection process and packing/logistics process. Assembly process consists of work assembling at horizontal or vertical side using manual tools at conveyor or worktable. In the inspection process, assembly-completed products are inspected with naked eyes or defect status is checked using an inspection device. If necessary, repair or impurity removing work can be conducted simultaneously. Logistics process consists of a process injecting parts or raw materials warehoused from a contractors' factory or raw material supplier using loading stand in the assembly process, and packing and loading work of products of which inspection was finished in the manufacturing

process. Logistics process mainly consists of transportation or loading of heavy stuffs.

To summarize design factors related to working area drawn from each process, the assembly and inspection processes are summarized as the height (vertical working area), width and depth (horizontal working area) of worktable. The design factors of logistics process can be summarized as the height and depth of loading and the height of transport facility handle. For worker-centered workplace design, anthropometric measurements need to be reflected so that all workers can easily and comfortably work in consideration of worker's characteristics by gender and age. This research designs workplace area by reflecting the anthropometric measurements of workers in their 20~40s in the electronic industry.

The 6th Size Korea (KATS, 2010) report provides the measurements of those who are in their 20s, for example, by dividing the group into 5 years of age difference, namely into 20~24 and 25~29, and then, provides the anthropometric measurements by 10 years of age difference (for example: 40~49 for those in 40s). To reflect the anthropometric measurements in 20~40s, there are a method to reflect the human body characteristics of the entire group of 20~40s, and another method to reflect the characteristics of 20s to 40s representing the groups of big (tall) people and small (short) people. This research designs working area using the anthropometric measurement types published by the 6th Size Korea report (KATS, 2010). In case workers belonging to male and females by age group with different anthropometric measurements work together in one workplace, the principle designing working area that can accommodate both big and small people can be applied. The comparison results of anthropometric measurements by 20s to 40s of male and female workers in the 6th Size Korea report show that the measurements are the biggest in the group of 20~24, and the smallest in the group of 40~49. If small people are represented, the 5%tile measurements of the 40~49 group corresponding to small people group of males and females can be used. When big people are represented, the 90%tile measurements of the 20~24 group of males and females can be used.

3. Results

3.1 Assembly workplace design

3.1.1 Horizontal working area

The thing to consider in designing working area related to the front of a worker in the electronic industry's assembly work is not to cause inconvenient working posture like excessive stretching worker's arm or bending worker's waist forward as shown in Figure 1. To this end, it is important to deploy worktable close to worker's body and at his/her waist height so that the worker can work within comfortable working distance. Work frequently conducted in designing working area should be located within the normal working area so that anyone can handle the work without stretching arm. Work conducted from time to

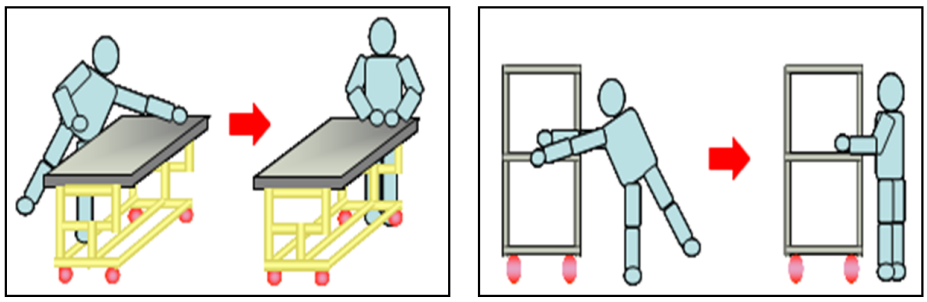

Figure 1. Inadequate and proper working posture

time needs to be deployed within the maximum permissible working area, which is limit that a worker can reach by stretching arm without bending waist forward.

To provide working area through which all male and female workers can comfortably work in a workplace, the elbow-grip length, which indicates the length that can handle hand with elbow contacting one's body, needs to be used (Figure 2).

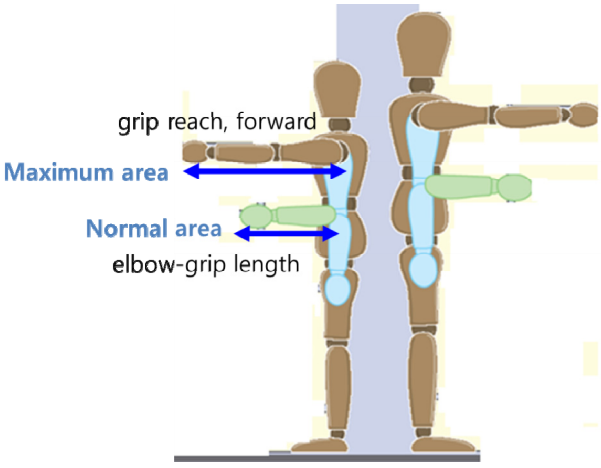

Figure 2. Elbow-grip length and grip reach, forward

The limit line can be set for normal working area, where all workers can work, irrelevant of age bracket of males and females, based on the smallest person. Consequently, design needs to be made, based on 27.5cm (Table 1), which is the 5%tile elbow-grip length value of the female 40~49 group, the smallest group among the group measurements by female and male age group demonstrated in the 6th Size Korea report (2010). For the maximum permissible working area for male and female workers, the grip reach, forward, which is the maximum permissible measurement that can grip by stretching hand as shown in Figure 2 is used. The maximum permissible section needs to be designed on the basis of the minimum measurement of small person group, if the maximum permissible section can be permitted to all groups. As a result, design needs to be conducted using 59.5cm, which is the 5%tile value of grip reach, forward of female group aged 40~49 as shown in Table 2.

Table 1. Normal working area - elbow-grip length

Age	Gender	Mean	Standard deviation	Elbow-grip length (mm)		
				5%tile	50%tile	95%tile
20~24	Male	339	18.6	310	338	370
	Female	312	14.5	289	312	335
40~49	Male	321	16.5	295	320	350
	Female	298	14.6	275	297	323

If large-sized products are produced like TV, the horizontal working area can exceed worker's maximum working area, when the

Table 2. Maximum permissible working area - grip reach, forward

Age	Gender	Mean	Standard deviation	Grip reach, forward (mm)		
				5%tile	50%tile	95%tile
20~24	Male	709	32.0	657	709	762
	Female	647	32.0	602	644	705
40~49	Male	689	32.1	635	690	740
	Female	641	27.7	595	639	693

worker works in front. Although, a male or female worker can undertake one person-completion type of work alone up to 59.5cm of horizontal working area, two or more of collaborative work is required to produce a product having horizontal working area beyond that in the case of considering male and female workers. Namely, if horizontal working area is 59.5cm and longer, it is desirable to make two persons in one unit work for collaboration. If working area exceeds 119cm, the selection and deployment of a male worker who can conduct 2 persons collaboration work is needed, or a proper action needs to be sought, since straight line distance becomes shorter, when a horizontal worktable is tilted.

3.1.2 Conveyor or worktable height

If conveyor height or worktable height is too low, worker's waist and neck are excessively bent, and if conveyor height or worktable height is too high, worker's shoulder goes up. For these reasons, worker's fatigue goes up and work efficiency is reduced. For workers with different physical conditions to comfortably work at one conveyor height, the conveyor height needs to be provided by selecting permissible section with which all workers can comfortably work. The height of worktable or the height of conveyor, where work is conducted, is designed on the basis of worker's elbow height. Simple assembly work carried out on the worktable should be designed about 5~10cm lower than the elbow height as shown Figure 3. In the case of precision assembly work, design needs to be made in line with worker's elbow height or a bit higher than the elbow height, which can be ideal.

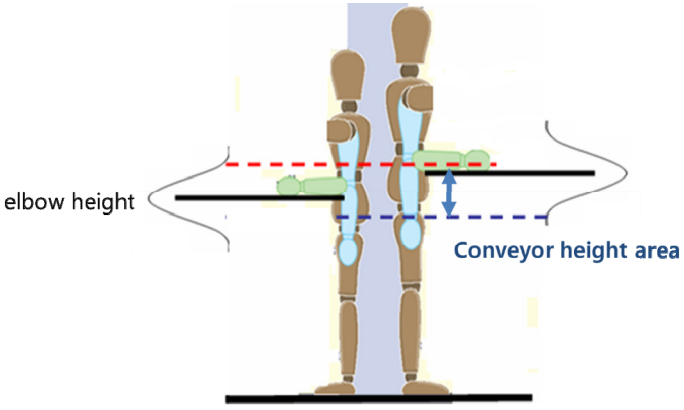

Figure 3. Elbow height and worktable (work surface) height

To calculate proper worktable height taking into account all males and females by age on both simple assembly and precision assembly work undertaken on the worktable, the scope commonly meeting male and female workers' permissible scope on the

basis of bent elbow height needs to be selected. Since elbow height is high in the 20~24 group by age, 5%tile should be set as lower limit, and 95%tile needs to be set as upper limit, because the 40~49 group's elbow height is low: then the scope can be the most appropriate section in terms of accommodation scope. If the worktable height is designed higher than low elbow height of older age group, and lower than high elbow height of younger age group, it can be the commonly permissible section for small people and big people. By gender, because females' measurements are smaller and males' are bigger, the entire permissible section needs to be set from the 5%tile of the male 20~24 group with bigger measurements to the 95%tille of the female 40~49 group with smaller measurements. According to anthropometric measurements by age and gender exhibited in the 6th Size Korea report (2010), 99.7cm (Table 3), the 5%tile of the 20~24 male group, with high elbow height, is demonstrated as minimum permissible scope, and 101.9cm (Table 3), the 95%tile value of the 40~49 female group with low elbow height, is demonstrated as maximum permissible scope. The appropriate worktable height that considers both males and females is between 99.7cm and 101.9cm; therefore, the common conveyor height for both males and females can be designed on the basis of 100~101cm, according to work type.

Table 3. Conveyor height - elbow height

Age	Gender	Mean	Standard deviation	Elbow height (mm)		
				5%tile	50%tile	95%tile
20~24	Male	1056	37.0	997	1056	1123
	Female	972	37.2	912	970	1034
40~49	Male	1036	41.4	971	1035	1108
	Female	961	36.1	902	960	1019

What is important in designing conveyor line design is that conveyor height plays a role of worktable height. The height of linear conveyor line, where assembly work is mainly conducted, needs to be set, based on work point height in the case of assembly work. For example, conveyor height is set based on PCB height in the process inserting parts to PCB. If assembly work point is to be in line with recommended conveyor height in order to assemble products with large volume like TV or refrigerator, not PCB of which height can be ignored, actual conveyor height needs to be set at the height deducting work subject height from the recommended conveyor height.

The conveyor height for assembly work has narrow accommodative scope, since the conveyor aims for all workers to undertake repetitive work in the section suitable for all of them. If assembly work is not conduced at a specific height, and occurs in another height, the worktable height design should be interpreted as a design problem on permissible working area. It is desirable to approach as a design problem on working area like the inspection worktable height design in terms of conveyor line height design that needs to change worktable height.

3.2 Inspection workplace design - vertical working area

For inspection work, marking devices and control devices related to inspection are designed at lower or higher height than normal height in many cases, due to worker's movement line and inspection facility characteristics like vertically erecting work to move a product to an inspection device or look at the product in various angles. Inspection work needs to approach as a problem to seek permissible work scope, rather than a problem setting a specific height like conveyor height. Although, it is desirable for inspection to be conducted at worker's elbow height like assembly work, if possible, inspection work demands vertical work section with larger scope than that in view of inspection work characteristics, frequent inspection work needs to be assigned in

the normal working area, which is recommended section. Inspection work conducted from time to time needs to be set as maximum working area, which is maximum permissible section. The recommended working area of inspection work should consider worker's fist height to acromion height corresponding to general arm action scope, and maximum action can be set from the floor to worker's stature corresponding to permissible action scope (Figure 4).

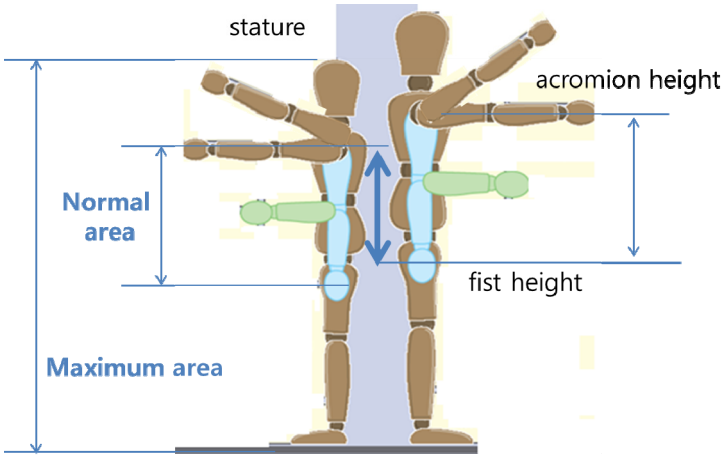

Figure 4. Inspection workplace design - fist height and acromion height

For recommended working area's lower limit to consider both male and female workers, the 95%tile of workers group with high fist height corresponding to minimum height that a worker can grab without bending is used. For the upper limit, 5%tile of the group with low acromion height is considered. In Table 4, 81.7cm, namely, 95%tile of the workers group aged 20~24 with high fist height, is selected as lower limit. For acromion height, which is upper limit, 5%tile of female group aged 40~49 with low acromion height, 119.0cm (Table 5) is considered: therefore, proper section becomes 81.7~119.0cm. The maximum working area needs to be set from the floor to stature. For the maximum permissible stature, 5%tile of female group aged 40~49, based on small people, 149.0cm (Table 6), is used. Namely, maximum working area is set from the floor to 149.0cm scope.

Table 4. Fist height

Age	Gender	Mean	Standard deviation	Fist height (mm)		
				5%tile	50%tile	95%tile
20~24	Male	766	32.0	713	768	817
	Female	709	32.4	655	710	764
40~49	Male	767	34.5	708	765	825
	Female	712	30.9	662	712	762

3.3 Working area design of material handling

In the material handling process, the guideline for design working area related to mainly heavy stuff, based on design factors such as the height and depth of loading and delivery equipment handle height, is presented. Pulling, pushing, pressing or moving

Table 5. Acromion height

Age	Gender	Mean	Standard deviation	Acromion height (mm)		
				5%tile	50%tile	95%tile
20~24	Male	1398	46.1	1323	1399	1476
	Female	1287	48.4	1209	1287	1370
40~49	Male	1369	52.8	1283	1368	1454
	Female	1261	44.0	1190	1260	1333

Table 6. Stature

Age	Gender	Mean	Standard deviation	Stature (mm)		
				5%tile	50%tile	95%tile
20~24	Male	1735	51.7	1651	1740	1817
	Female	1604	52.7	1515	1605	1699
40~49	Male	1692	56.8	1599	1691	1785
	Female	1567	49.9	1490	1566	1648

actions are conducted, when a heavy stuff is used or handled, and movement distance reduction is helpful to time savings and work hazard reduction in handling heavy stuff. For this reason, it is good to handle heavy stuff at waist height close to worker's body, if possible. From a human dynamic aspect, even the heavy stuff with the same weight causes bigger load to human's lumber, if it is away farther from human body. Therefore, in the case of handling heavy stuff, it may have significance to set permissible limit in handling heavy stuff, based on no good condition, rather than optimal condition, from a preventive aspect. Namely, it is good to set weight, corresponding to permissible handling limit in each section based on worker's working area and then to design loading work.

Figure 5 shows the degree of ease in handling heavy stuff by working area section presented by British HSE (2004). The height area of optimal section, in which a worker can use strength the most efficiently in handling heavy stuff, is from worker's fist height to elbow height, and recommended section is from knee height to acromion height. The lower limit of optimal section is the 95%tile of fist height of big male group aged 20~24, which is 81.7cm. The upper limit is the 5%tile of elbow height of small female group aged 40~49, which is 101.9cm as shown in Table 3. Namely, it can be ideal to handle heavy stuff in the section between 81.7cm and 101.9cm. The lower limit of the recommended section is to be set at the 95%tile of knee height of big male group aged 20~24 (49.5cm as shown in Table 7), and the upper limit can be set at the 5%tile of acromion height of small female group aged 40~49 (119.0cm). The recommended heavy stuff handling section is set between 49.5~119.0cm.

4. Conclusion

Looking into recent workplace, workers' mean age becomes older, and female workers are increasing. Consequently, the era selecting workers meeting work requirements shifts into the era to design working area so that even a weak and not strong novice can easily work.

If working area design that considers worker's ability is not carried out, it becomes difficult to ensure desired productivity and

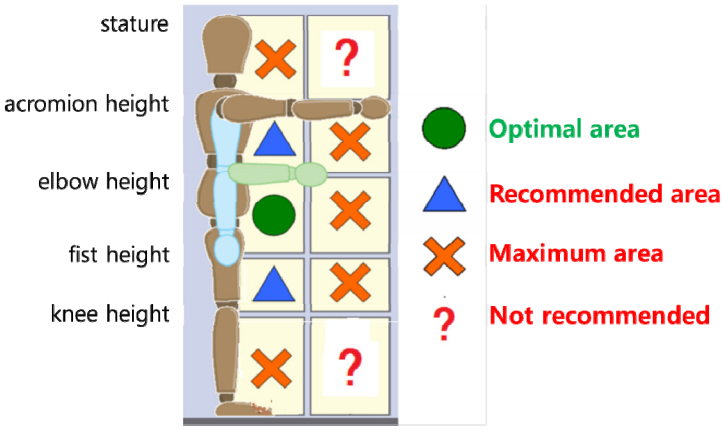

Figure 5. Working area of material handling (HSE, 2004)

Table 7. Knee height

Age	Gender	Mean	Standard deviation	Knee height (mm)		
				5%tile	50%tile	95%tile
20~24	Male	460	21.9	425	459	495
	Female	414	22.5	378	414	452
40~49	Male	432	260	388	432	475
	Female	401	208	363	403	434

quality, and work-related disease may occur, while a worker cannot endure work requirements. Worker-centered workplace design taking into account worker's physical ability can be a key to ensure work productivity, product quality and work safety.

Because many problems that can be easily solved exist, if difficult work at worksite was considered in the design stage, people need to be interested in ergonomic work method from the design stage. Work improving activities through worker-centered design brings about the same effect as the activities for productivity improvement. Therefore, a guideline for design of working area is needed in order to improve workplace, where workers can easily and comfortably work.

This research presented a method to apply the work-centered design concept to electronics manufacturing line workplace. Actually, the guideline for horizontal and vertical working areas design was presented by reflecting Koreans' anthropometric measurements in the assembly, inspection and logistics processes in the electronic industry. However, this research limitations in that the research subject was limited to the electronic industry workplaces manufacturing products using conveyor lines, this research considered only males and females in their 20~40s and drew only design measurements related to working area.

Researches on various industries and work types are considered necessary, and further research on broader range of age brackets needs to be conducted. This research also has limitation in that worker-centered design considering only worker's physical safety and convenience was presented. Further research on worker's cognitive characteristics, as well as applied principles on anthropometric measurements, need to be undertaken.

Nevertheless, the guideline for working area design presented in this research can be used as a guideline for actual design variables to be applied to working area. Also, the design principles and procedures drawn according to worker's characteristics by gender or age can be applied. From these aspects, this research is considered meaningful.

Acknowledgements

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