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ENHANCING VISUAL INSPECTION CAPABILITIES FOR PARTICLE DETECTION IN TRANSPARENT LIQUIDS

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บทคัดย่อ

การตรวจจับอนุภาคขนาดเล็กด้วยสายตามนุษย์ยังได้รับความนิยมในปัจจุบันเพราะเป็นงานตรวจสอบที่ไม่ซับซ้อน อย่างไรก็ตามยังมีความผิดพลาดของมนุษย์เกิดขึ้นได้ในการตรวจจับอนุภาคในของเหลวใสไม่มีสีในบรรจุภัณฑ์เช่นน้ำเกลือในถุงนิ่ม การศึกษานี้จึงได้ทำการทดลองหาปัจจัยที่ส่งผลต่อความสามารถของพนักงานและออกแบบวิธีการทำงานของพนักงานเพื่อเพิ่มความสามารถในการตรวจสอบด้วยสายตา การดำเนินงานวิจัยเริ่มจากคัดเลือกพนักงานเพศหญิงอายุระหว่าง 25 ถึง 30 ปี ที่มีค่าสายตาปกติ เพื่อเข้าร่วมทดสอบการทำงานตรวจจับอนุภาคที่ปะปนในน้ำเกลือบรรจุในถุงนิ่ม โดยใช้สถานีทดลอง 16 สถานี ตัวแปรต้นในการทดลองได้แก่ (1) ท่าทางในการตรวจ (2) ระยะเวลาในการตรวจจับ (3) ระยะเวลาพักสายตา และ (4) แสงสว่างที่ใช้ ผลการวิจัยพบว่าปัจจัยที่มีผลต่อการตรวจผิดพลาดได้แก่ ท่าทางในการตรวจและระยะเวลาพักสายตา ซึ่งควรออกแบบวิธีการทำงานให้มีลักษณะดังนี้ 1) ให้เวลาพักสายตา 2 นาทีทุกการทำงานหนึ่งชั่วโมง และ 2) ไม่ใช้ท่าทางอิสระในการตรวจแต่ให้ใช้ท่าทางที่กำหนดและมีตะขอช่วยแขวนให้ชิ้นงานที่ตรวจอยู่ระดับสายตา ซึ่งพบว่า ค่าความสามารถในการทำซ้ำและค่าความไม่ลำเอียงของผู้เข้าร่วมการทดสอบมีแนวโน้มที่ดีขึ้น ส่วนค่าความผิดพลาดมีค่าลดลงเหลือ 0 – 3% สำหรับกลุ่มผู้เข้าร่วมทดสอบที่มีประสบการณ์สองปีขึ้นไป ส่วนในกลุ่มที่มีประสบการณ์น้อยกว่าสองปีมีค่าความผิดพลาดลดลงเหลือ 5% เท่านั้น และพบว่าข้อร้องเรียนประเภทอนุภาคปนเปื้อนลดลงจาก 45% เหลือเพียง 5% ภายในระยะเวลาหนึ่งปีหลังการปรับปรุง

คำสำคัญ: ความผิดพลาดของมนุษย์; การตรวจจับด้วยสายตา; การตรวจจับอนุภาคขนาดเล็กในของเหลวใสไม่มีสี

ABSTRACT

The visual inspection of small particles is still used in some uncomplicated work nowadays. However, human error can still occur in detecting particles in clear, colorless liquids in packaging such as saline in soft bags. The objective of the study was to increase visual inspection capabilities and to improve the working stations for reducing human error in particle detection of saline in soft bag. In the first step of the research, 25 to 30-year female operators who had normal eyesight would perform the inspection of the saline in transparency soft bags in 16 working station conditions at eye height sitting position. The independent variables were the inspection postures, detecting time, rest time, and brightness. The results showed that the factors which affect detection error were posture and rest time. Moreover, the improved working station was the fixed posture with using a hook that had a better result than

the freestyle posture and the suitable rest time was 2 minutes for everyone working hour. After improvement, the value of repeatability and attribute tended to increase. For detection error, it was decreased from 5-8% to 0-3% in the ≥2 years' experienced group and from 13-18% to 5% in <2 years' experienced group. In one year after improvement, the complaints from customers about particles decreased from 45% to 5%.

KEYWORDS: Human error; Visual inspection; Particle detection in transparent liquids

1. Introduction

The visual inspection method is considered to be a simple quality tool used in production due to its easy use and suitability for uncomplicated tasks. On the other hand, some limitations do not assure the error caused by humans [1]. Humans have limitations in physical properties such as the field of view, tolerance from long last working, etc., and mental properties such as tolerance from doing a repeating job, and prudence. Other factors that cause human error are a bad working environment, low brightness causes their eyes fatigue and stress [2]. There are some studies showed that continuous working and having less rest time maybe cause body stress and low efficiency [3]. Normally, solutions are putting the right man on the right job, adjusting the workstation, and providing eye rest time [4-5]. To measure the success of performance improvements may be measured by Reduce human error, speed up quality inspection, reduce inspection error, etc.

Visual inspection is still common for inspection of liquids contained in transparent packaging. For consumer health, strict particle detection is important in cases whenever the fluid is intended for ingestion, including injections like as medicine, clear solutions, or saline [6-7]. It's possible that the particles in the liquid are microscopic fragments of a bottle, cap, or bag.

This research focuses on finding work conditions for reducing human error in visual inspection of salt in soft bags as the last step before it is delivered to customers or patients. There must be no small particles, insects, paper, plastics, etc. in the product solution. In addition, the research also covered increasing human capacity and reducing fatigue.in the inspection as well.

According to the retrospective data, the inspectors had malfunctions which were observed from the results of repeated inspections, and it was discovered that 20% of saline bags containing tiny particles pass detection. The most obvious undetected particles are fibers, followed by small black particles. The inspectors worked with freestyle postures according to their aptitude. The research also compared the freestyle pose with the proposed new pose.

The ability of the participants was analyzed and evaluated using measurement system analysis (MSA) to measure the results of this study. MSA is well-known for implementing quality control to ensure that quality system criteria are met [8-9]. MSA has the advantage of eliminating the variety of operators, methods, and work conditions. In terms of definition, all operators may perform the same task or do it repeatedly. The response variables are repeatability, detection error, and attributability [10-14].

The first section of this paper gives an overview of the above-mentioned visual inspection error problem. Theory and related research are described in the second section. The third section is about the research methodology, and the fourth section is about the results and discussion. The final section contains the conclusion.

2. Theory and related research

2.1 Human limitations in visual inspection

Normally, the visual inspection is consisting of 4 steps; 1) Screening 2) Detection 3) Identification, and 4) Decision. However, this procedure does not assure 100% quality due to human limitations [15]. Decision-making human errors in inspection can be divided into two categories [16]. The first category is the poor quality item can pass the inspection. The second type is a good item, but the inspector judges it to be of poor quality. Both two categories of human error occur in simple visual inspection at a rate of 3 to 10% and occur in complicated visual inspection at a rate of 20 to 30%. However, training and improving the workstation will help to reduce these errors.

In general, work stress can be caused by both physical and mental causes, for example, repetitive tasks in strenuous tasks can impair operators' abilities. Therefore, the improvement of work should be done not only to improve the work station, but also to the proper working methods and rest periods.

Eyesight limit; both up-down and left-right viewing angles impair vision and induce neck and back muscle fatigue or damage. Providing suitable posture such as standing, sitting, and so on, that would improve the efficiency of human activities [17].

Anthropometric data; statistic anthropometric data is used to design a working station in which the operator has a little movement body such as reading, small pieces assembling, polishing jewelry, etc. The body measurement (in Figure 1) was used in this design of the experiment.

- **Standing height (A)**
- **Sitting height (B)**
- **Shoulder level, Sitting (C)**
- **Eyesight level, Sitting (D)**
- **Weight (E)**

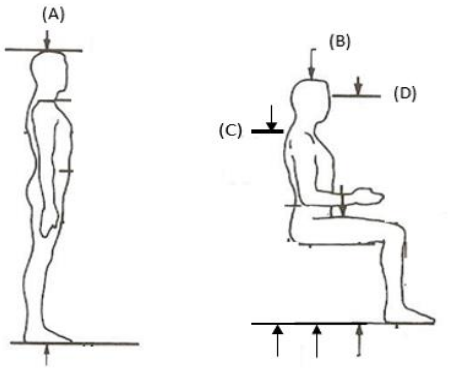


Figure 1 Anthropometric data

2.2 Measurement Analysis System

MSA is a tool for ensuring that quality control results are valid and trustworthy. Repeatability, Attribute, and Reproducibility are the indicators in the MSA. The capacity to repeat testing in one individual with the same sample is referred to as repeatability. The attribute is used to evaluate the operator's abilities and to compare the operator's inspection accuracy to the reference. The average measurement of the same sample examination from different inspectors is known as reproducibility. The appraiser variation is indicated by the reproducibility. As there were multiple operators in this study, certain errors might arise as a result of operator

variance. MSA's indications were utilized to screen participants before to their participation in the study. In addition, Repeatability and attributability were employed in certain studies to assess visual inspection ability. Moreover, the detection error indicates the accuracy and the mistakes of the operator. It was discovered that following the training, repeatability rose from 70% to 90%, and inspection mistakes fell from 2.31 percent to 1.06 percent. To reduce fluctuations due to human error, the levels of indicators may be utilized as criteria for visual inspection recruitment in the future.

$$\%\ Repeatability = \frac{No.of\ times\ that\ get\ same\ result\ for\ each\ person}{No.\ of\ all\ samples} \times 100 \quad (1)$$

$$\%\ Attribute = \frac{No.of\ times\ that\ get\ same\ result\ and\ correctly\ for\ each\ person}{No.\ of\ all\ samples} \times 100 \quad (2)$$

$$\%\ Detection\ Error = \frac{No.of\ times\ that\ get\ result\ correctly\ for\ each\ person}{No.\ of\ all\ samples} \times 100 \quad (3)$$

3. Research Methodology

3.1 Participants

The participants in this experiment were four females aged 25 to 30 years. The participants were divided into two groups; ≥2 years' experience group who had experience in visual inspection work of at least two years and <2 years' experience group who had experiences in visual inspection work less than two years. Both groups had similar anthropometric data (Table 1) and all participants would be passed the acceptance criteria for the testing in visual inspection ability.

In the testing of visual inspection ability, all participants had to inspect 20 soft bags using in free-style posture during the testing. These bags consisted of 14 good bags, 3 bags were contaminated white particles and the rest 3 bags were contaminated black particles. The size of these particles was more than 50 microns that could be detected with eyesight in a clarity cabinet.

Table 2 states the acceptance criteria for testing of visual inspection ability. There are three indexes; 1) Operator Effectiveness, O_E = Number of right decision / Number of all samples 2) False Alarm Index (I_{FA}) = Number of negative errors / Number of all samples, and 3) Index of a Miss (I_{MISS}) = Number of positive errors / Number of all samples. The participant will be denied since O_E becomes less than 80%, I_{FA} is more than 10%, and I_{MISS} is more than 5%.

Table 1 Anthropometric data of four participants (unit: cm)

(a) Less than 2 years' experience group

Body proportions	Mean	Median	Min	Max
A	160.3	160.3	159.5	161.0
B	124.5	124.5	124.0	125.0
C	96.5	96.5	95.0	98.0
D	111.8	111.8	111.5	112.0
E	53.0	53.0	52.0	54.0

(b) More than 2 years' experience group

Body proportions	Mean	Median	Min	Max
A	161.8	161.8	160.5	163.0
B	124.3	124.3	124.0	124.5
C	98.0	98.0	97.0	99.0
D	111.3	111.3	109.5	113.0
E	52.5	52.5	51.0	54.0

Table 2 Acceptance criteria for the measurement system [18]

O_E	I_{FA}	I_{MISS}	Decision
$\geq 90\%$	$\leq 5\%$	$\leq 2\%$	Acceptable
$\geq 80\%$	$\leq 10\%$	$\leq 5\%$	Semi-acceptable
$< 80\%$	$> 10\%$	$> 5\%$	Unacceptable

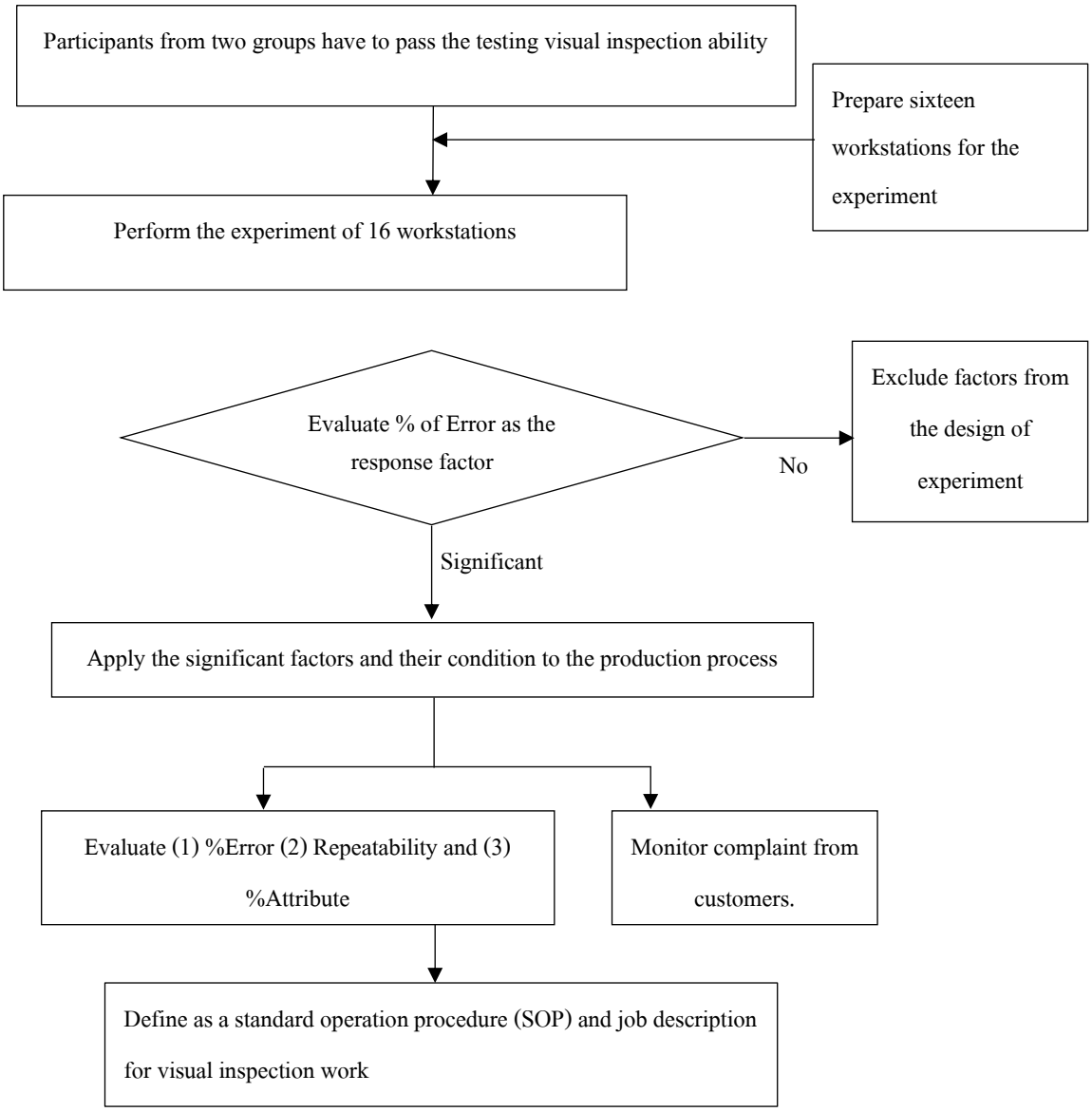


Figure 2 Research methodology

3.2 Factors and experimental design

This study used the 2k factorial design with 16 treatments [19]. Each treatment was repeated 2 times (n=2). The response variable was %error while the influencing variables were posture, detecting time, resting time, and brightness. In the other hand, the prior inspection has already used 2 background color (black and white) and no hook using.

Posture : there were 2 postures, free-styles (no hook) and proposed posture which can reduce the fatigue and stress refer to Figure 3. The operator would inspect by holding the bags with the hook in eyesight level and visualize on the bag from top to bottom and bottom to top respectively at white and black background.

Detecting time : the detecting time implies the time uses for inspection the particles. There were two levels; 5 and 10 seconds for each bag. Time-consuming inspections resulted in reduced production. On the other hand, if it takes less time, there would be more human errors. The detecting time used in prior production is 7 seconds.

Resting time : in visual inspection work, the main organ used is eyesight. It may cause fatigue due to long time working. The resting time is the time for the eyes to rest for a short time. There were two levels; 1 and 2 minutes per working hour. The rest period used in the past is one minute per working hour.

Brightness : brightness is an attribute of the visual working area. It was measured at the middle of the inspection cabinet. There were two levels; 2,000 and 3,500 lux. The brightness used in prior production is 2,500 lux.

4. Results and Discussion

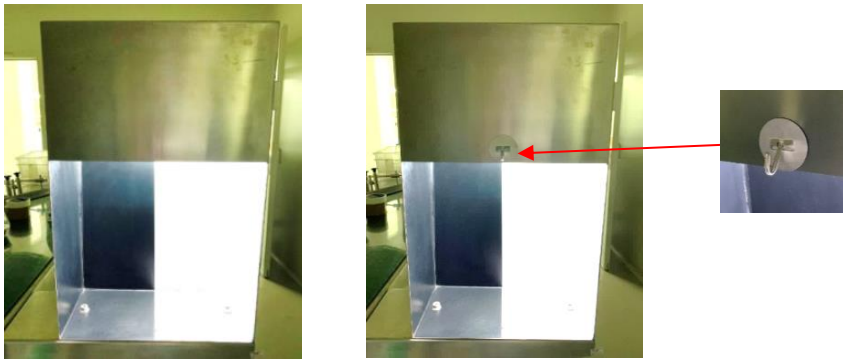
4.1 Various contaminated particles

Various contaminated particles were discovered on both black and white backgrounds in the experiment, as shown in Figure 4. Fibers, scraps, and other particles were observed after saline was contained in bags. These contaminants were believed to be defects in the soft bag manufacturing process.

4.2 Visual inspection ability of participants

From Table 3, the participants assigned to the acceptable group to join the experiment was Ms.A, and Ms.B, Ms.C, and Ms.D were defined in the semi-acceptable group according to criteria in Table 2. The reason was that Ms.B did not focus on the experiment while both Ms.C and Ms.D did the wrong procedure such as not cleaning the bag before inspection or not being in picking up the bag, causing bubbles. Therefore, training was provided for Ms.B, Ms.C and Ms.D to be able to participate in the experiment.

In addition, I_{FA} values were greater than I_{MISS} values (Table 3). Both of groups were found to be more likely to have negative errors in visual inspection because they misunderstood the bubbles and white dust in the saline softening sac.



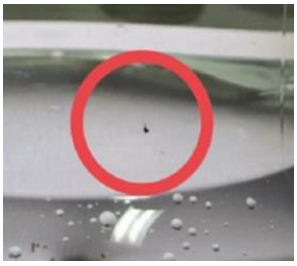
a) no hook b) hook

Figure 3 Locating a hook

(a) White fiber on black background

(b) Black fiber on white background

(c) White scrap on black background



(d) Black scrap on white background

(e) Other particles on black background

(f) Insect remains on white background

Figure 4 Type of particles in saline soft bags

Table 3 Result of visual inspection ability analysis

	≥ 2 years' experiences		< 2 years' experiences	
	Ms.A	**Ms.B**	**Ms.C**	**Ms.D**
O_E	95.00%	92.50%	87.50%	85.00%
I_{FA}	5.00%	5.00%	7.50%	10.00%
I_{MISS}	0.00%	2.50%	5.00%	5.00%

4.3 Response variables

From Table 4, percentage of detection errors was obtained as response variable. It was clear that treatment no.1 and no.5 stated the worst percentage of errors was 10% from Ms.C and Ms.D respectively with the one minute resting time per one working hour and using free style posture. The result confirmed that the more resting time, the more reducing eyesight fatigue for a long time working. For a fixed hook, it was an equipment that helps operators to lift or hold the bags during visual inspection. It could also reduce muscle fatigue and hurt. Moreover, using fixed posture provided operators a correct posture. Then the two minutes resting time and using fixed posture with hook in workstation would be applied to production scale.

For the detecting time and brightness variables, these values were insignificant to the inspection results (percentage of human errors). The conventional operation takes 5 seconds per bag for inspection, and for the inspection time is 3,500 lux (according to USP37 regulations it should be 2,000-3,500 lux). Therefore, these values would continue to be used in production scale.

Table 4 Result of the experiment with sixteen working station conditions

					%Detection error (≥2 years' experiences)		%Detection error (<2 years' experiences)	
Treatment	**Rest time (Min)**	**Detecting time(Sec)**	**Brightness (Lux)**	**Posture**	**Ms.A**	**Ms.B**	**Ms.C**	**Ms.D**
1	1	5	2000	Free	3.33%	6.67%	6.67%	10.00%
2	2	5	2000	Free	0.00%	0.00%	3.33%	6.67%
3	1	10	2000	Free	3.33%	0.00%	3.33%	3.33%
4	2	10	2000	Free	3.33%	3.33%	6.67%	3.33%
5	1	5	3500	Free	6.67%	6.67%	10.00%	6.67%
6	2	5	3500	Free	0.00%	6.67%	3.33%	6.67%
7	1	10	3500	Free	0.00%	6.67%	6.67%	3.33%
8	2	10	3500	Free	3.33%	0.00%	3.33%	3.33%
9	1	5	2000	Fix	3.33%	0.00%	3.33%	3.33%
10	2	5	2000	Fix	0.00%	0.00%	3.33%	3.33%
11	1	10	2000	Fix	0.00%	3.33%	3.33%	0.00%
12	2	10	2000	Fix	0.00%	0.00%	0.00%	3.33%
13	1	5	3500	Fix	6.67%	0.00%	6.67%	3.33%
14	2	5	3500	Fix	0.00%	0.00%	3.33%	0.00%
15	1	10	3500	Fix	3.33%	3.33%	3.33%	6.67%
16	2	10	3500	Fix	0.00%	0.00%	3.33%	3.33%

From Figure 5, ANOVA table shown that rest time and postures had a small P-value (less than 0.05) in both groups. The equation shows the relation between %detection error with rest time and the posture in two groups as below

Less than 2 years' experience group

$$\%Detection\ error = 4.374 - 0.833\ Rest\ time - 1.041\ Posture + 0.000\ Rest\ time \times Posture \quad (4)$$

More than 2 years' experience group

$$\%Detection\ error = 2.188 - 1.146\ Rest\ time - 0.938\ Posture - 0.104\ Rest\ time \times Posture \quad (5)$$

Rest time (2 min = +1, 1 min = -1)

Posture (Fixed posture = +1, Free style posture = -1)

The above equations explains that there is more rest time and there is a hook to help hold the saline bag, thus reducing work errors. The positive results were more pronounced in the experienced group than in the inexperienced group. and may further explain that the experienced group was able to perform better work postures than the inexperienced group. Therefore, a clear work methodology is useful for those with no work experience or less than two years of experience workers. The improvement in production scale should be conditioned with an emphasis on rest time and hook setting at the eyesight level for reducing arm/shoulder muscle fatigue.

Analysis of Variance (<2 years'exp)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	48.5806	4.8581	3.90	0.073
Linear	4	35.3833	8.8458	7.10	0.027
Rest time	1	11.0889	11.0889	8.89	0.031
Detecting time	1	6.2500	6.2500	5.01	0.075
Light intensity	1	0.6972	0.6972	0.56	0.488
Posture	1	17.3472	17.3472	13.91	0.014
2-Way Interactions	6	13.1972	2.1995	1.76	0.275
Rest time*Detecting time	1	2.7722	2.7722	2.22	0.196
Rest time*Light intensity	1	2.7889	2.7889	2.24	0.195
Rest time*Posture	1	0.0000	0.0000	0.00	1.000
Detecting time*Light intensity	1	0.6889	0.6889	0.55	0.491
Detecting time*Posture	1	6.2500	6.2500	5.01	0.075
Light intensity*Posture	1	0.6972	0.6972	0.56	0.488
Error	5	6.2334	1.2467		
Total	15	54.8140			

Analysis of Variance (≥2 years'exp)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	50.3445	5.0344	2.74	0.139
Linear	4	40.9736	10.2434	5.58	0.044
Rest time	1	21.0222	21.0222	11.45	0.020
Detecting time	1	1.5625	1.5625	0.85	0.399
Light intensity	1	4.3264	4.3264	2.36	0.185
Posture	1	14.0625	14.0625	7.66	0.039
2-Way Interactions	6	9.3709	1.5618	0.85	0.582
Rest time•Detecting time	1	4.3472	4.3472	2.37	0.185
Rest time•Light intensity	1	1.5500	1.5500	0.84	0.400
Rest time•Posture	1	0.1722	0.1722	0.09	0.772
Detecting time•Light intensity	1	1.5625	1.5625	0.85	0.399
Detecting time•Posture	1	1.5625	1.5625	0.85	0.399
Light intensity•Posture	1	0.1764	0.1764	0.10	0.769
Error	5	9.1820	1.8364		
Total	15	59.5265			

Figure 5 Analysis of variance

4.4 Post-improvement result

Table 5 shows the results after implementing the 2 minutes of rest time, fixed working posture with a hook used in the production scale. The %repeatability and %Attribute were increased to 95-100% in the ≥2 years' experience group and 90% in the <2 years' experience group. For the %error, the value was decreased to 0-3% in the ≥2 years' experience group and 5% in the <2 years' experience group. The remaining error was still caused by muscle fatigue but the rest time used was not affected the productivity.

Table 5 Visual inspection ability after improvement

	%Repeatability	%Attribute	%Detection error	
Ms.A	95%	95%	3%	≥2 years' experiences
Ms.B	100%	100%	0%	
Ms.C	90%	90%	5%	<2 years' experiences
Ms.D	90%	90%	5%	

5. Conclusion and suggestion

To improve the visual inspection of clear liquid in packaging like saline in soft bags besides controlling the environment such as; brightness and selective operators, the posture and rest time are also important factors. The posture during the inspection should be a fixed pattern by inspection at eyesight level and provides a hook for holding the bag at eyesight level and not excess eyesight limit. This equipment could support the arm and shoulder from fatigue and muscle injuries.

More rest time would recover the operator's eye from fatigue. The resting time was changed to 2 minutes per working hour which had no effect on production capacity. In the experiment, during 2 minutes break, the participants would be allowed to close their eyes and stay in their chairs only.

Moreover, it should be aware the using white background for inspection because it causes an error more than using black background. When inspection with white color background, the operator have to visualize two times on the bag from top to bottom and bottom to top respectively.

After the improvement in rest time and posture, it was found that the errors from the inspection of operators were decreased and the risk of using contaminant products in patients or customers will also be reduced. Figure 6 shows that customer complaints about particles in packaging are reduced sharply from 45% to only 5% for one year after improvement.

There are three recommendations for this research. The first point is that this improvement can be applied to other production lines, such as inspecting rigid bottles, glass containers or transparent containers with different package sizes. The second point is that training on visual inspection should be carried out periodically to maintain inspection capability and to be used in the training

of inexperienced operators. Lastly, bubbles can be mistaken for white dust when a white background is used to indicate particles in a clear liquid, more likely to result in visual errors than when a black background is used. Therefore, during visual inspection, the liquid in the package should not move around to avoid air bubbles.

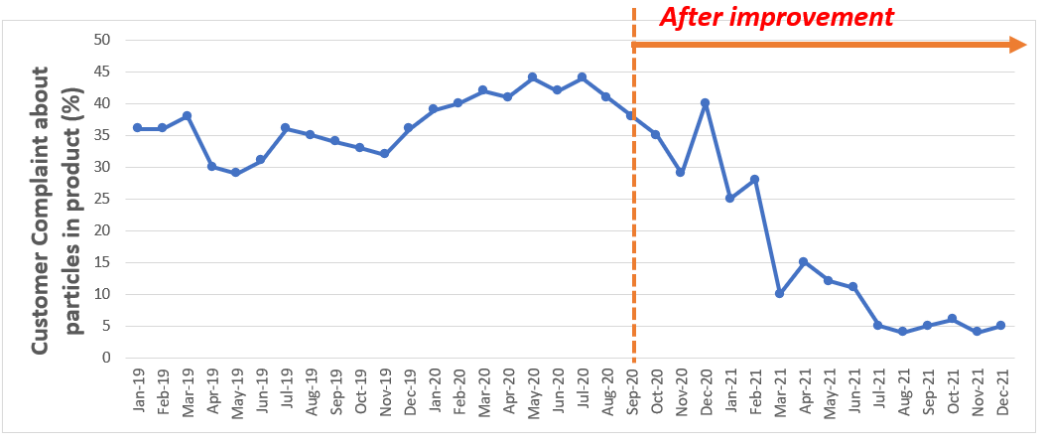


Figure 6 Particles in product complaint compared with all customer complaint

Conflict of interest

The authors declared that this article has no conflict of interest.

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