Body posture analysis during visual control of fruit and vegetables at different directions and speeds of conveyor belt transport

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Abstract - Kurzfassung

Visual quality control of fruit and vegetables is a complex task. Reliability is important to sustain quality standards. Usually the quality control is followed by or carried out after other mechanized processes like washing or packing. The expectations on the worker's performance are influenced by the machine capacities. Nevertheless work place design is conservative even in modern plants; products are commonly transported on conveyor belts passing the worker from the left to the right or the other way around. Thus the man-machine-interface often becomes a constructive shortcoming. Based on literature the superiority of a changed product transport, namely moving the products towards the worker, was to be examined. A motion analysis was carried out to measure differences in the body postures as well as the amount of movements for the variations of product transport. The influence of the transport direction was very strong, resulting in a 100 % larger sum of motion per piece if the goods passed the worker from the right side. Most efficient and most comfortable proved to be the transport direction towards the worker.

Keywords: Continuous flow production, direction of transport, motion analysis

Körperhaltungsanalyse während der visuellen Qualitätskontrolle von Obst und Gemüse an Fließbändern mit unterschiedlichen Transportgeschwindigkeiten und -richtungen

Die optische Qualitätskontrolle von Obst und Gemüse ist eine vielfältige und anspruchsvolle Arbeitsaufgabe. Eines der wesentlichen Kriterien ist die Zuverlässigkeit, um innerhalb der Verfahrenskette nachhaltig den Qualitätsstandards gerecht zu werden. Für gewöhnlich ist die Qualitätskontrolle in die maschinelle Aufbereitung eingebettet. In sehr traditioneller Weise werden die Produkte auf Förderbändern an der Arbeitskraft vorbeigeführt und von ihr begutachtet. Die Anforderungen an die Arbeitskraft sind hoch und sie ist stark an den Takt der Maschinen gebunden. Häufig entstehen hier konstruktive Engpässe, da die Maschinenleistungen im Zuge der Technisierung stark gesteigert wurden, die menschliche Sortierleistung jedoch nur über die Anzahl der Arbeitskräfte zu erhöhen ist. Basierend auf Hinweisen aus der Literatur wurden konstruktive Veränderungen des Sortierarbeitsplatzes untersucht. Hierfür wurden drei unterschiedliche Materialtransportrichtungen bei drei Geschwindigkeiten bewegungsanalytisch untersucht. Die Ergebnisse zeigten einen starken Einfluss der Transportrichtung auf den Bewegungsaufwand. Am günstigsten bewertet wurde die Transportrichtung von vorne auf die Arbeitskraft zu. Im Vergleich hierzu betrug der Bewegungsaufwand bei gleicher Aufgabenstellung für die Transportvariante von rechts nach links mehr als das Doppelte. Auch die Körperhaltungsanalysen sprachen für die technisch aufwändigere Variante der Produktzuführung von vorne.

Schlüsselwörter: Fließbandarbeit, Transportrichtung, Bewegungsanalyse

1 Introduction

Post harvest processing of fresh fruit and vegetables includes washing, sorting and controlling before the products are packed. In order to meet the quality standards defective or unsuitable fruits must be removed from the production line. The processing is mostly organized as continuous flow production.

Within the last decade washing, sorting and controlling were successfully mechanized for many products, basically for those with simple geometrics like apples, tomatoes or oranges. Products with uneven shape (i.e. carrots), a long stem (i.e. leek) or those that come in pairs (i.e. cherries) still need to be sorted by hand (Kleisinger 2001). This is usually done by groups of sorters inspecting the goods visually as they pass in front of them on conveyor belts. The visual inspection process is often combined with turning the products to view the underside, or the separation of connected batches to allow consecutive single processing.

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Throughout this process the inspectors have to make a large number of decisions in a short period of time. Additionally the job is highly repetitive and little challenging. The performance requirements are high, and have been increasing due to rising machine capacities, which mostly depend on the manual processing beforehand. According to work organizational standards (Hettinger & Wobbe 1993) the common situation for visual inspection or handling of products along conveyor belts is little satisfactory for the workers. The work cycle is predetermined by the machine capacity, there are no buffer areas to allow individual work routines and the workers usually work and get paid in teams.

The evaluation of continuous flow processing is based on the results of scientific research, which was carried out in the 60's and 70's of the last century (i.e. Megaw 1979). In consequence the high division of labor was generally questioned and slowly disestablished. Future design and development were focusing on the automation of the described work to avoid the adverse effects of labor division.

In addition to the negative effects of continuous flow production the environmental working conditions in processing plants are often noisy, draughty, cold, wet and/or dusty, depending on crop and machinery (Miller 1989). Finally many parameters and procedures need to be studied to optimize inspector productivity, accuracy and comfort.

Meyers et. al. (1986) carried out a literature review on information about ergonomic guidelines regarding dynamic visual inspection. A lively discussion regarding visual inspection was found in the 70's. Many studies have been performed relating rotation and translation, width and spacing, illumination and regarding work groups, but for the typical inspection table only, where the products are viewed from the side. Meyers and his colleagues found a 25 % increase in accuracy of detecting defective produce, when the products were moving towards the inspector from the end.

Miller (1989) and Naugle & O`Brien (1976) precisely described the problems of quality grading in horticultural crops, concluding that a lot of work for ergonomists is left to improve and maintain grading performance. Although his work was carried out twenty years ago, it still describes a current issue.

The optimization of the design of grading tables was again tackled by Studman (1998) in a pilot study, but the ongoing mechanization seems to have stopped further efforts to improve work place design for visual inspection. Although Studman also favored a cascade system in his conclusions, based on significantly higher comfort of the sorters, the traditional way of passing products from left to right or the other way around is still privileged in modern plants.

The automation within the processing chain is progressing creating more and more men-machine-interfaces. Therefore the work situations along the processing chain continuously change and the workers have to quickly adapt to that (Jakob & Geyer 2007). Currently researchers and plant developers pay little attention to the design of the remaining manual processes. The development is mainly focusing on the machines, resulting in rapidly increasing capacities and in consequence the need of higher material input as well as higher performances for those jobs carried out manually along the assembly line (Jakob & Geyer 2006). This reveals the basic phenomenon that work design in the manufacturing environment is traditionally technology-driven, focusing on machine capacities but neglecting the role of people in production processes (Paquet & Lin 2003).

Quite often it is found that machine capacities are larger than the possible performance achieved due to bottlenecks along the processing line (Jakob & Geyer 2005). If so, a very common idea of the leading hand to increase the output is boosting the speed of material transport, forcing the workers to increase their performance. Apart from the speed of material transport the work place design plays a very important role for optimal work performance.

Due to the work tasks, which include minimal action but high repetition, it is hard to measure performance. A busy looking worker might not work efficiently. Naugle & O`Brien (1976) found that the time needed for grading strongly depends on the inspectors and not on the amount of defects. Time studies, a common method for measuring performance, are hard to realize for fruit grading, because the process times are very short. Other tools like video and motion analysis are therefore necessary to objectively judge the work performance or comfort.

The organization of the manual work becomes more and more challenging. There is the necessity to improve the situation for the workers regarding health, comfort and job satisfaction as well as increasing the work performance due to highly efficient machines. Based on the cited literature the superiority of a changed product transport, namely moving the products towards the worker, was to be examined. The main objective of the motion analysis was to evaluate efficiency and comfort during task performance for different directions and speeds of product transport to be able to quantify the impact of variations.

2 Method

2.1 Motion analysis

Via motion analysis the amount of motion and body postures were analyzed regarding three different ways of presenting products for visual quality control. A standard conveyor belt was used with adjustable speed control. The motion analysis was carried out using a software-based system implementing passive retro reflective markers. The worker, equipped with markers (Fig. 1 a), was filmed with two digital video cameras (Canon XM 2). Based on the two videos the positions of the markers were detected and calculated by the Software SIMI motion (Unterschleißheim, Deutschland) and described as 3-D-room coordinates. The raw data was then transformed into indicators allowing interpretation. The worker's front and backside were filmed. The head-on projection was used to analyze the working area, whereas the back projection served to analyze the body posture. For the head on projection the markers were attached on both arms and the head (see Fig.1 a). When the back was filmed the markers were positioned on both shoulders, on the hips and along the spine. Therefore it was possible to measure bending as well as torsion. The main focus of the motion analysis was to describe the body postures, the line of sight and the area of activity.

2.2 Experimental setting

The defined work task was altered from controlling products by sight, because this kind of action is not traceable. Instead an active task was chosen to allow objective process control. The performed work routine was clipping on short pieces of plastic piping onto plastic brackets used for electrical installation. 35 brackets, 10 per meter, were heterogeneously attached to the conveyor belt during one measuring run. The worker was instructed to fill all brackets using both hands. The pieces of plastic piping were kept in a bag in front of the worker's abdomen. The bag contained more brackets than needed for one measuring run.

Speed and direction of transport were varied. The adjusted speeds equaled work capacities of 1500, 2250 and 3000 pieces per hour; the conveyor belt was respectively running at 0.4 and 0.6 and 0.8 m/s over ground. At the highest capacity the worker was unable to complete the work task, the medium speed was just viable and the lowest speed could represent the recommended rate to completely do the job.

The working width of the conveyor belt was 35 cm, the height 92 cm, adjusted according to DIN 33406 (1988) and the size and elbow height of the subject. All experiments were carried out with one subject only; each variant was repeated 10 times. The subject was right handed.

The three directions of transport were towards the worker (↓), a so called cascade system, and from left to right (→) and right to left (←).

2.3 Analysis and statistics

For data analysis several parameters were calculated based on the 3-D-room coordinates.

To measure the effort the sum of motion was calculated, defined as the sum of the distances between all measuring points.

To describe the body posture the upper arm elevation, the elbow flexion/extension and the head inclination were calculated. The upper arm elevation is a three point angle based on an elbow, a shoulder and a hip marker. The elbow flexion/extension is based on three markers attached on the wrist, the elbow and the

a **b**

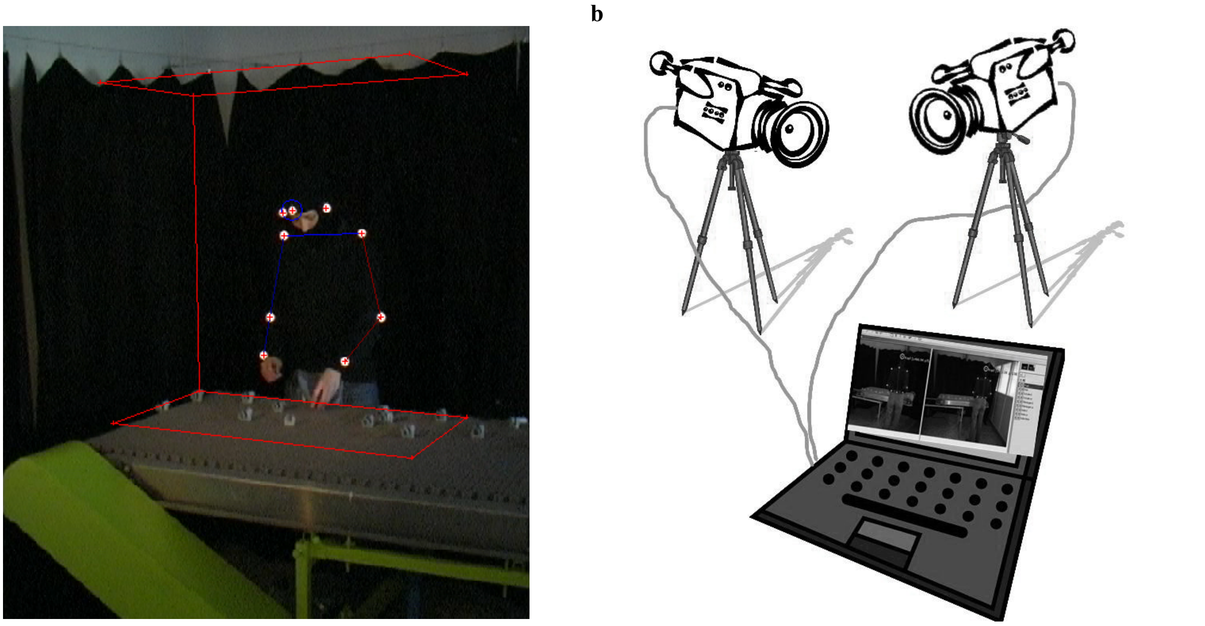

Fig. 1a + b: Screenshot visualizing marker positions and calibration system (a), schematic experimental set up of video based motion analysis (b) shoulder, respectively named the opening angle of the arm.

The head inclination is calculated from the back projection of the worker, based on three markers fixed on the head, the neck and the spine approximately at L1. An angle of 180° corresponds to an upright position, the worker looking in front direction (horizontal optical axis = 0°). With a relaxed head position the angle referring to the trunk axis ranges between 165 and 170°. Thus, the head is slightly bent forward, the horizontal optical axis lying on a lower level. The relaxed head position implies a normal optical axis of 25 to 35° (Bokranz & Landau 1991). According to DIN EN 1005-4 (2005) the acceptable area ends at 40° respectively to the horizontal optical axis. All measured angles below 140° therefore have to be classified as not acceptable if the worker is doing the job for a longer period.

A one-factorial variation analysis was carried out to determine the impact of the direction of transport. It was based on two hypotheses H0: all transport directions show the same average impact and H1: the transport directions cause a difference on the average values. The total variation, the variation within the factor and between the factors were calculated and compared. The smaller the mean square variation within the factor (MS_{within}) is in comparison to the mean square variation between the factors ($MS_{between}$) the bigger is the factor impact described by the ratio $F_{emp} = MS_w / MS_b$. If $F_{emp} > F_{krit}$ the hypotheses H1 is true for the critical percentage. If $F_{krit} = F_{0,99}$ there is a 99 % probability, that the transport direction influences the results.

3 Results

3.1 Time need and motion effort

The three different speeds of the conveyor belt result in theoretical processing times per piece of 2.4 s, 1.6 s and 1.2 s, respectively. The calculated time need, determined by the use of Methods Time Measurement (MTM) according to Luczak (1993), ranges with approx. 50 TMU (1.8 s per piece). A proper MTM calculation in this case is difficult because the intervals for bringing and putting cannot be determined exactly. This is due to the movement of the conveyor belt and the uneven distribution of the brackets over the whole belt width of 35 cm.

Nevertheless, after watching the worker, the speeds can be roughly classified into “not fully stretched”, “fully stretched” and “overworked”. This classification represents the rating of the test person as well as that of observers. At highest speed the test person was hardly able to fill all the brackets. Consequently a full work performance could not be guaranteed.

A comparison of the sums of motion for the different transfer directions, measured at the wrist markers, showed the lowest motion effort with the conveyor belt moving towards the worker (Fig. 2).

Furthermore, the overall effort diminished with increasing belt speed. This becomes most evident with the transfer direction “moving towards the worker” in Fig. 2.

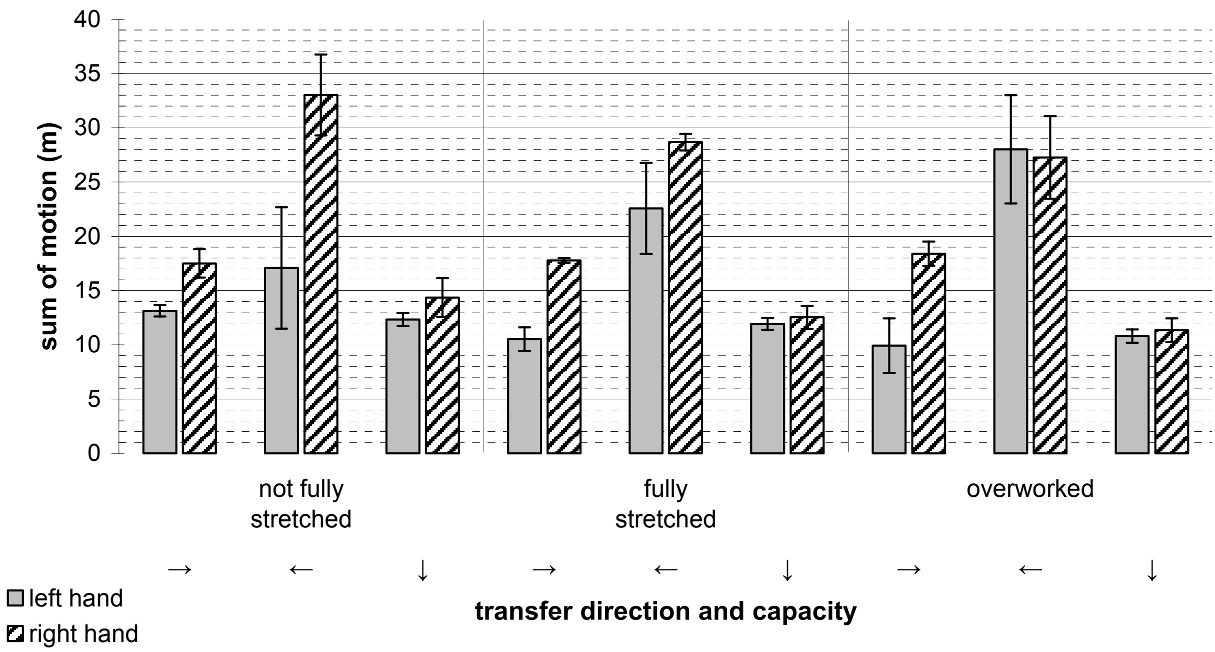

Fig. 2: Average values of the sums of motion for the hands during one representative measurement at different speeds and transfer directions

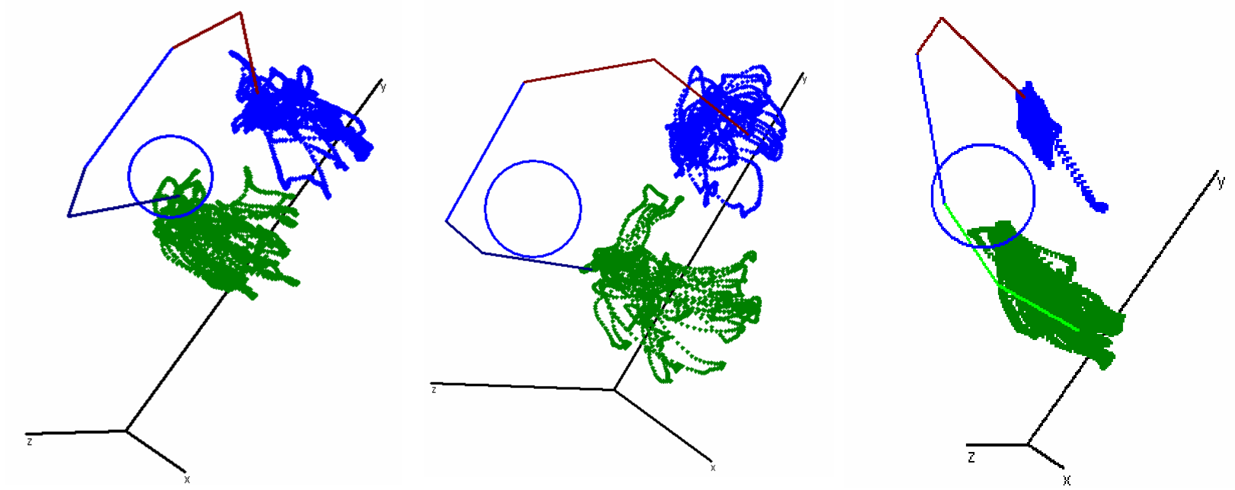

Fig. 3: Screenshots of motion traces for both hands at different transfer directions (arrow) and the lowest belt speed for one measuring run

However, observation revealed that with increasing speed not all brackets could be filled successfully. In consequence the actual work effort was diminished, being a possible reason for the lower sums of motion.

Fig. 2 also displays the uneven distribution of workload between the left and the right hand. This strongly depends on the direction of transport. Remarkable is the strong difference between the sums of motion for the transfer direction from right to left in comparison to the other transport directions. The difference between left and right hand becomes smaller with increasing belt speed. The sum of motion for both hands is nearly twice as high for the direction from right to left in comparison to the rest.

The average values for the sum of motion all refer to the handling of 35 pieces or the manageable amount. The observed test person is right handed, a possible explanation for the constantly larger values of the right hand.

Fig. 3 visualizes the hand movements. The motion traces for the left and right hand are displayed looking at the worker from above. When the material passes the worker from left to right or the other way around, a more uneven distribution of work for the left and the right hand is observed. The situation is worse, when the conveyor moves from right to left.

The complete division of labor between the hands becomes evident as the areas of work for each hand do not overlap at all. The middle picture in Fig. 3 shows that the far area of the belt is worked only by the right hand, but the left hand is also filling brackets. The motion traces for the hands referring to the opposite direction of product transport reflect the results shown in Fig. 2. The right hand fills the brackets, while the left hand solely supplies the material. The workload is therefore much higher for the right hand than for the left hand.

3.2 *Body posture*

The analysis of the body posture is very complex and shall be presented by using different examples mainly focusing on the worker's comfort. It is generally found that almost all measurements result in larger ranges between minimum and maximum values of different body angles (e. g. shoulder-hip-angle or shoulder axis in relation to xy-plane) for the transfer directions "passing the worker from the sides".

According to common methods of risk assessment the trunk and head inclination and the upper arm elevation will also be presented and compared with normative values.

The comparison of the upper arm elevation between the different material transport directions shows higher values for the direction from right to left. Table 1 shows the average values of the complete measuring cycle, the recorded minima and maxima as well as the differences between minima and maxima. Values above 60° are not recommended. For the transport direction from right to left during 8 % of the working time the upper arm elevation exceed 60°. The maximum values of the upper arm elevation for the transport directions left to right and towards the worker stay below 60°.

In Table 2 the average, minimum and maximum values for the opening of both arms and for the three transport directions are listed. The average values for both arms are similar, when the products are passing the worker from either side. The range between minimum and maximum is larger for the transport direction right to left. This also explains the large sum of motion shown in Fig. 2.

Fig. 4 to 6 present the maximum and minimum angles of the head axis in relation to the trunk axis for the different transfer directions. Furthermore, they contain the respective average values and its linear trend.

Table 1: Elevation of the upper arms for different directions of material transport

	Direction of material transport					
	Towards the worker		Left to right		Right to left	
	Right arm	Left arm	Right arm	Left arm	Right arm	Left arm
Average	18.9°	22.1°	29.7°	23.0°	26.4°	29.5°
Minimum	9.7°	13.9°	13.3°	14.6°	0.4°	7.2°
Maximum	30.8°	36.6°	54.0°	38.9°	92.8°	88.1°
Range	21.1°	22.7°	40.6°	24.3°	83.1°	72.9°

Table 2: Opening angle of the arms for different directions of material transport

	Direction of material transport					
	Towards the worker		Left to right		Right to left	
	Right arm	Left arm	Right arm	Left arm	Right arm	Left arm
Average	105.8°	116.8°	118.5°	105.4°	116.8°	104.6°
Minimum	77.7°	85.1°	85.1°	82.2°	59.3°	50.2°
Maximum	142.3°	151.7°	156.2°	140.1°	160.1°	166.3°
Range	64.6°	66.6°	71.1°	57.9°	100.8°	116.1°

Within Fig. 4-6 strongly differing results are found. The largest range between minima and maxima is again found for the transport direction from right to left (Fig. 5). In opposite to the other transport directions the linear average is increasing here. The average angle for the head position still stays below the values for the opposite transport direction. The closest to a relaxed head position (165-170°) is found for the transport direction towards the worker (Fig. 6). The influence of the speed of transport is rather small. No significant differences are found for either variable. A comparison of all values is shown in Fig. 7. The larger range between minimum and maximum for the transport direction from right to left is visualized by the size of the box.

4 Discussion

A good working environment as well as adequate training and instruction are a solid basis for constant and high work performance. There are many factors that influence the worker's performance. Some of them are listed in Fig. 8 (Miller 1989).

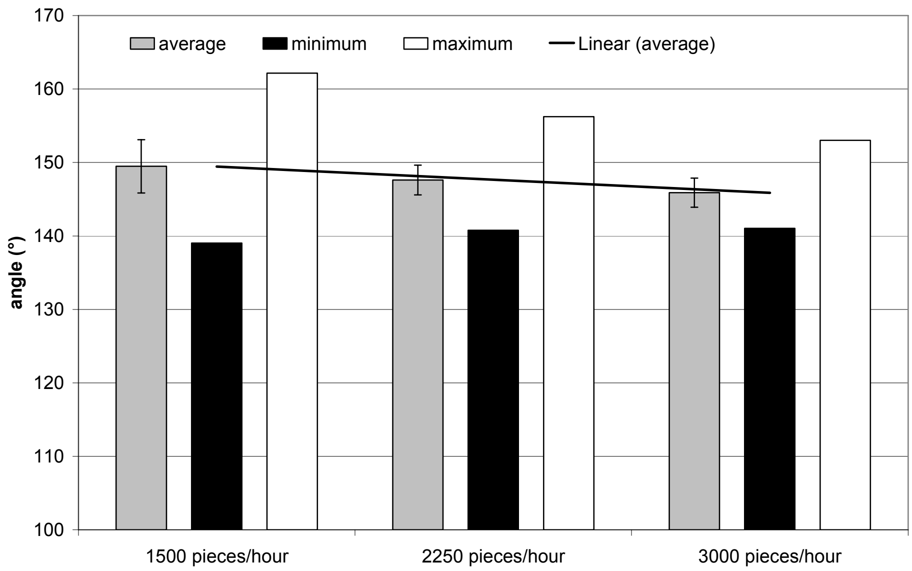

Fig. 4: Head inclination in relation to the trunk with belt moving from left to right at three different speeds for three measurement routines per speed

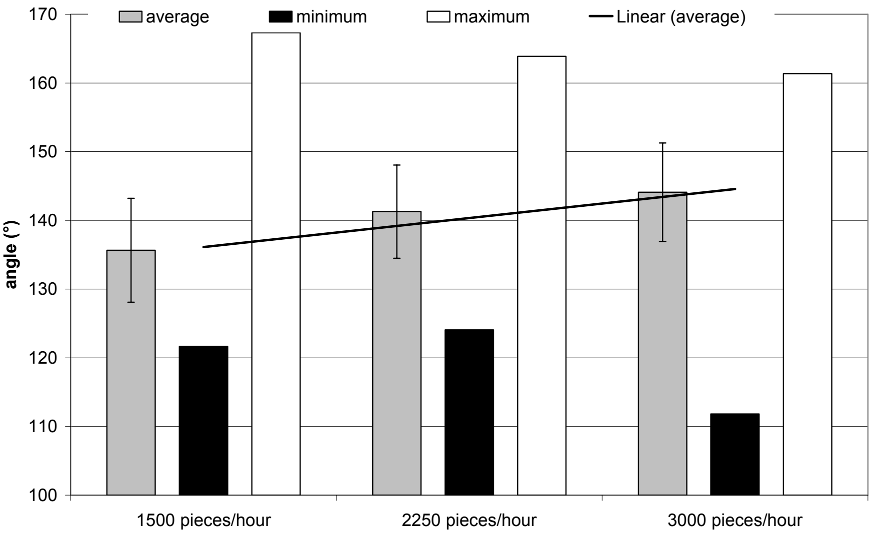

Fig. 5: Head inclination in relation to the trunk with belt moving from right to left at three different speeds for three measurement routines per speed

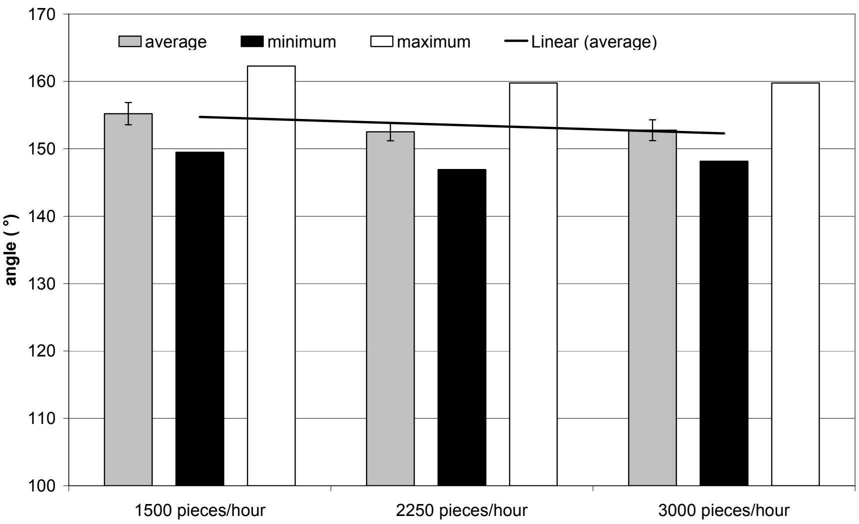

Fig. 6: Head inclination in relation to the trunk with belt moving towards the worker at three different speeds for three measurement routines per speed

The results of the experiments show, that the speed of material transport as well as the direction should be carefully planned and adjusted to fit the task and the worker's performance.

Via motion analysis several indicators were collected and are now discussed to help improving the design of man-machine-interfaces as well as to avoid unfavorable working postures.

The sum of motion indicates the necessary effort to fulfill a task, but the extent of motion is also correlated with individual performance factors. Since the task was the same for the experimental layout, differences in the sum of motion can be related to the work style, skill or other performance factors.

The comparison of different transport directions based on the sum of motion clearly indicated the advantages of a belt moving towards the worker. On the one hand the motion effort was lower; on the other hand the work distribution between the hands was more even (Fig. 2 and 3). Nevertheless, if the sum of motion is used to compare the work effort, it has to be taken into consideration that in periods when the worker is not fully stretched he/she tends to unnecessary actions trying to keep up the performance. Video monitoring showed that in these cases the worker left the optimal working area when the task was completed quicker than the belt supplied new material.

The motional expense for the hands showed a large variation for the different transport directions from left to right and opposite (Fig. 2). One of the major reasons for this uneven distribution is most likely based on the preference of one hand. In our case the test person was right handed. If instead the material reached

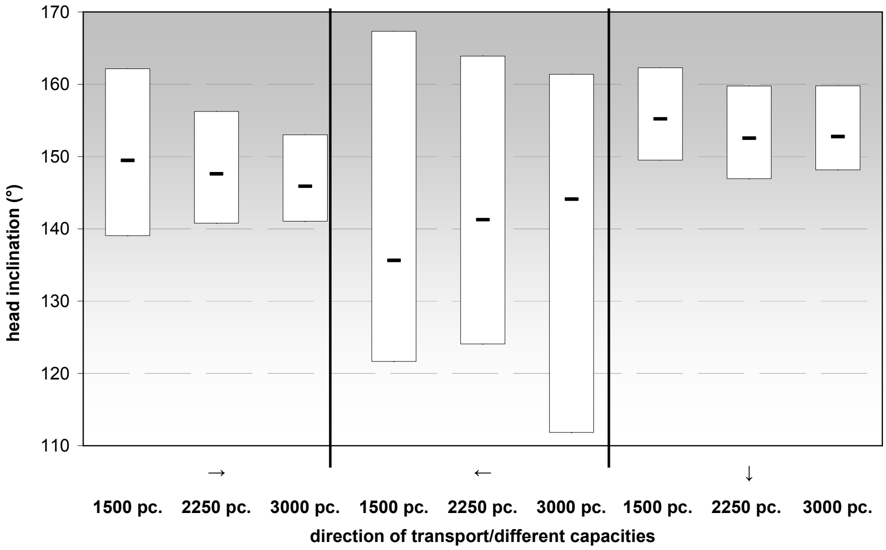

Fig. 7: Average angle of head inclination for 1500, 2250 and 3000 pieces per hour for the three transport directions and the range of the head movement displayed by the box (minimum and maximum)

the worker from the front, the motion tracks were evenly distributed, proving the ability of both hands to do the same job. In case of material supply from the sides the right hand was taking over a larger amount of the work task. Again the difference was even bigger when the material passed the worker from the right side. The amount of motion for both hands was 100 % larger in this case compared to the direction towards the worker. In other words this means that it is possible to reduce the effort per piece by 50 % if the right setting is chosen. These results are undermined by earlier investigations (Jakob & Geyer 2005) having shown that a greater potential for a performance increase is achieved if the worker has a synchronous work style.

The one-factorial variation analysis of the overall motion effort for both hands proved the strong impact of the direction of transport, based on the ratio (F_{emp}) of the mean square deviation within the factor (MS_w 3,18) and the mean square deviation between the factors (MS_b 7796,40) of $F_{emp} = MS_w / MS_b = 2448,3$. Since MS_w is much smaller than MS_b, the impact of the examined factor is proven.

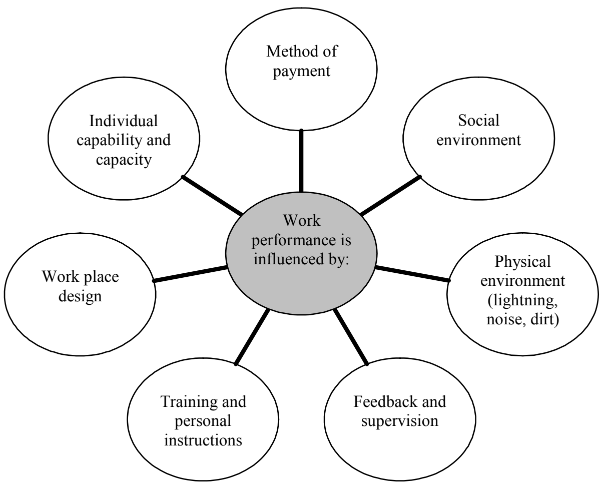

Fig. 8: Factors influencing the work performance of visual inspection or related processes

The amount of motion is an important parameter to measure efficiency. Process times for reaching and bringing are mainly influenced by the distance traveled. The sum of motion also allows evaluating the expenses regarding the physical effort, which is again correlated with stress and strain.

The results of the parameters describing the body posture (Fig. 4 to 6 and Table 1 and 2) also speak in favor of a transport direction towards the worker.

The measured head inclination for the belt moving towards the worker (Fig. 6) corresponds to a more relaxed position (DIN EN 1005-4). It has to be kept in mind that this kind of work is related to a high frequency of motion, the existence of an obligatory pulse and a one-sided body posture. In their sum those parameters can quickly lead to a higher workload having negative consequences on the worker's performance. Thus, measures of better design are important.

The differences between the transport directions left to right and right to left were most impressive. The test person was right handed representing around 85-90 % of the population. If the goods were passing the worker from the right, the right hand was doing most of the work (Fig. 3). The sum of motion (Fig. 2) was significantly higher resulting in a higher effort per piece and a lower possible output. Looking at different parameters describing the body posture alarming values were found for the upper arm elevation for this experimental setting. For about 8 % of the whole day the work posture was classified as not acceptable because of the upper arm elevation and the high repetition. In addition to that the trunk inclination increased with the belt speed (no figure). The worker was also twisting the upper body, which was noticed during the video monitoring but hard to measure. Not acceptable values (DIN EN 1005-4) were also found for the head inclination when the products moved from right to left (Fig. 7). Values below 140° should be avoided, if the machine is used for a longer period.

The obvious preference to use the right hand was continuously reflected in all results. The impact of the work speed was much smaller. As it was described by Studman (1998) and Meyers et al. (1986) a greater level of comfort for the workers as well as a higher performance can be achieved if the products are moving towards the worker.

5 Conclusions

The experimental results lead to the conclusion that the use of cascade systems could bring an improvement of sorting or handling goods. Nevertheless, the use of those systems requires a technically more complicated realization and a higher flexibility concerning the number of workers as in those cases every worker needs his/ her own conveyor belt. This new study is based on numerical parameters collected by an objective method. The results enable to explain the preference for one or the other setting. In consequence practitioners should realize that the handedness of the worker has a superior importance in particular in plants where conveyors are utilized from both sides. Training or targeted selection of workers is necessary to guarantee constant work performance. Apart from a lower performance stress can cause discomfort for the worker if he or she is positioned on the wrong side of the belt.

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