Field study of age-differentiated strain for assembly line workers in the automotive industry

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Abstract. A field study in an automotive supply industry company was conducted to explore age-differentiated strain of assembly line workers. Subjective and objective data from 23 female workers aged between 27 and 57 years were collected at the workplace belt buckle assembly during morning shifts. Subjects with medication or chronic diseases affecting heart rate and breath rate were excluded. For subjective data generation different questionnaires were used. Before the Work Ability Index and the Munich Chronotype Questionnaire were completed by the subjects. Short questionnaires (strain-ratings, NASA-TLX) directly at begin and end of the work were used for obtaining shift-related data. During the whole shift (6 a.m. – 2.45 p.m.) bodily functions were logged with a wireless chest strap. In addition, the motion of the hand-arm-system was recorded for 30 times, 3 minutes each after a fixed time-schedule. First results show that younger subjects need significant less time for assembly (mean = 14.940 s) compared to older subjects (mean = 17.040 s; t(472.026) = -9.278 , p < 0.01).

Keywords: field study, aging, assembly, subjective and objective data

1. Introduction

Considering the demographic aging of Germany, by 2030 one third of the employed persons will be older than 50 years [29]. Hence, companies in Germany face both the challenge to maintain future productivity of their processes and to ensure the competitiveness of their products.

To investigate, whether decreasing physical performance influences the work process or whether work performance can be sustained through compensatory effects, will be part of this development. Empirical findings for decreasing physical performance with increasing age are available for the ability categories strength and flexibility [1,5,7,22,26,32]. Examining the neuromuscular performance, numerous analyses have confirmed a relation between age and decreasing stimulus-response time [8,10,21,28]. If one considers the increasing automation, the shorter cycle times and miniaturization, more importance has to be attached to neuromuscular performance [17]. In

previous studies, for example, by Pierson & Montoye (1958), it has been demonstrated that the minimum reaction time and the maximum movement speed are reached by 20 years of age, afterwards the performance values constantly deteriorate with increasing age. In addition, Cooke and colleagues (1989) showed that movements of subjects over 60 years of age become increasingly inharmonic and they more often misjudge distance (hypermetria).

Current research from the priority program „Age-Differentiated Worksystems" also shows a decreasing movement speed with increasing age but suggests an age-independent increase of the error rate with growing subject distance [4].

Considering the state of research there are only insufficient answers in relation to an age-differentiated design of tasks and work processes [9]. Numerous studies, confirming a decreasing performance of older people, have been conducted during laboratory tests. However, it should be emphasized that isolated tests of tempo-based basic functions do not allow any

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conclusion on work performance [12,14]. Research shows that older persons perform even better in realistic planning tasks than do their younger counterparts [13]. Work performance and age do not necessarily have to show negative correlations but rather strongly depend on work demands. Various studies support this theory [20,31,34]. These studies are in agreement with assumptions of an extended stress-strain model by Rohmert (1974). Due to miscellaneous basic conditions and multi-dimensional task structures in the working world, employees are able to vary working conditions and subject-related behavior. It remains in question however, which role task demand (short-cycled, repetitive tasks with high demands on sensory motor skills) and load duration play. Thus, there is need for further research from the authors' point of view. Graf (1955) and Jong (1959) have already documented in the 1950s the higher recovery-effective time of waiting of younger employees compared to older employees because of faster working. First examinations do not give satisfying answers, which tasks are age-critical and thereby eventually leading to "losses of time". Physical performance limitations and associated losses of time can efficiently be minimized by the choice of work method. A relation between work method and execution time was outlined in studies by Gilbreth [3].

The present field study, conducted in cooperation with an automotive supplier, was carried out within the DFG priority program 1184 "Age-Differentiated Work Systems". The study itself focused on the examination whether older employees are more stressed than younger employees during an eight-hour workload at an assembly line work station. To describe and structure manual work processes, the MTM-method (Methods-Time-Measurement) with the MTM-basic motions was employed. Furthermore, it has been analyzed to what extent employees are able to adapt to the work system through individual action regulation and whether older employees' extensive experience influences this process. The results can be used to better consider the needs of elderly people when planning and allocating work stations with high age-critical movements in future.

2. Methods

2.1. Subjects

Participants were recruited at a subcontractor in the automotive industry in Saxony (East-Germany). Due to the unequal distribution of men and women in this factory the study focused on the larger group of women. All 54 female assembly line workers from the workplace "belt buckle assembly" were invited to informative meetings during their working time and asked to participate voluntarily in the study. A prerequisite was, however, that they were trained for more than two months at the examined workplace to ensure that they are well-trained in the sense of MTM. 38 workers gave written informed consent but six left the factory before the study began. Therefore, 32 participants were sent to medical investigation (e. g. PPI-test, height, weight, discomfort of shoulder, arm and hand). However, five subjects changed their mind and refused to participate. Four workers were excluded from the study due to their medical condition or medication possibly affecting the heart frequency or breathing rate. Finally, 23 well-trained female workers aged 27 to 57 years (mean = 43.9 years, SD = 6.82 years) without any health problems took part in the study.

2.2. Workplace

The "belt buckle assembly" was chosen within the plant of the cooperation partner from the automotive supply industry for observation at the workplace because many of the performing tasks are age-critical MTM-basic motions of the hand-arm-system (see Fig. 1). An analysis of age-related changes of human abilities (e. g. vision) based on the "Chemnitz Age Database" [19] in alliance with the MTM-basic motions (e. g. reach) was carried out previously. The single-work-stations were arranged in two groups of four surrounded by a common assembly line to take completed pieces off. As a group the subjects had to assemble a given number of belt buckles within an eight-hour shift but where free to determine their individual working speed. Four workplaces were watched simultaneously. Two workplaces were chosen from each group to ensure that assembly worker were exempted from restocking the basic modules and research technique did not interfere with the production process.

Investigated workplaces were named A/B and C/D for data acquisition. The data presented in this paper are obtained from workplaces C and D. Nine several types of belt buckles were assembled at both identical workplaces C and D. About 9 to 11 single pieces were assembled manually. The workers were either sitting or standing in front of an assembly desk which was documented. In front of the workers were several small load carriers with the single pieces arranged.
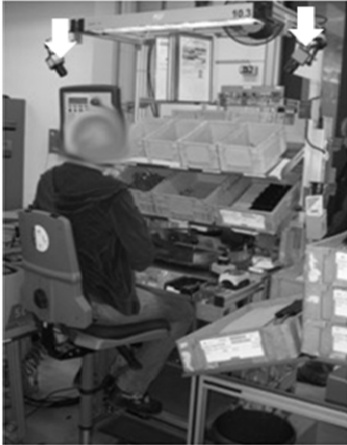
Fig. 1 Workplace belt buckle assembly (No. D), position of cameras is shown by white arrows

The stock above was filled up by Kanban-System as well as the pre-mounted basic modules provided on the right-hand side. The belt buckles were assembled on the desk in about 35 seconds and placed down on the continuously moving belt-conveyor on the left-hand side.

To record the motions of the hand-arm-system two cameras were attached at each workplace. Four workplaces were equipped with cameras and could be viewed at the same time.

2.3 Instruments

2.3.1 Objective measurements

The Aquila-Complete-System for motion recording consists of two linked computers accessing eight synchronized cameras. The software was developed specifically for this study by FusionSystems. A certain time schedule was defined to record automatically the sequences of operation 30 times per shift (distributed evenly over the shift, breaks were considered) with a duration of three minutes each. Additional manual recording was possible. Four workplaces were monitored at the same time. The videos documented the mode of operation and showed whether the production process was running smoothly.

Two experimenters were present to observe the full eight-hour shift. The observation protocols completed by the experimenters include information about changes of the belt buckle type and further, concerning the subject, conversations, briefly leaving the workplace or strenuous movements during regular assembling. Every hour temperature and the average noise of a five-minute-period were notated. A 433 MHz Temperature Station and a calibrated hand-held analyser for noise level measurement from Brüel & Kjaer version 2250-L were used for this purpose.

The bodily functions heart rate and breathing rate were logged once per second with the wireless Bioharness™ chest strap from Zephyr™ during the entire morning shift.

2.3.2 Questionnaire data

Different questionnaires were used to collect subjective data. The Work Ability Index was determined by the short-form of WAI [16] and filled in at home and brought to the medical investigation. The maximal possible score was 49 points. By means of strain-ratings [23] and TLX (NASA Task Load Index) [15], the individual subjective strain was measured at the day of investigation. The strain-ratings included 12 items and were completed shortly before and after the shift and showed the degree of the actual strain on a scale from 1-6. The TLX contained 7 items which were asked after the shift and the answers were a measurement for the past strain during the observed shift (scale 0-20). The individual chronotype was detected with the MCTQ (Munich Chronotype Questionnaire) [25] which was completed at home.

2.4 Procedure

Data were gained within nine weeks from January to March 2011 during ongoing production. For all subjects, observation and measurements were carried out at least twice during entire morning shifts (6 a.m. – 2.45 p.m.) without disturbance of the production process. The subjects completed the strain-ratings shortly before the shift in a separate room. Afterwards, the chest strap was activated and fixed around the subject´s chest underneath the clothes. The subjects went to their workplaces and fulfilled their normal assembly work wearing the comfortable strap over the next nine hours, which means during working time and breaks. After 4 – 4.5 hours the logging unit at the chest strap was displaced by a fully charged logging unit. Movements of the hand-arm-system were recorded with the cameras for the 30 defined checkpoints distributed over the whole shift. After the shift the chest strap was detached, data were transferred to a computer and straps were washed for sanitary reasons. The subjects were asked to complete the strain-ratings a second time and for

additional information the TLX. The WAI and the MCTQ were filled in at home some other day.

2.5 Analysis

Bodily function values from the chest strap were transferred in an excel chart, synchronized with the 30 recorded checkpoints and analyzed. Within each video check point of three minutes 5-6 belt buckles were assembled. Within each motion recording, showing regular work, the assembly of one belt was randomly selected for analysis. Data of times with irregular work, e. g. distraction through conversation were not analyzed. The two greatest common denominators of the watched movements of the hand-arm-systems (MTM-motions) were analyzed and compared between two age-groups. Period No. 1 covered seven basic MTM cycles, period No. 2 three basic MTM cycles with pressing in one cycle. Data presented in this paper refer to period No. 1. The assembly time required for period No.1 within the belt buckle (compare 2.2 workplace) was determined with the video records.

For identification of the individual variance in mode of operation sequence of assembly, arrangement of load carriers and other noticeable behavior, e. g. storing two different sorts of single pieces in one carrier, was recorded. Subjects were free to choose a sitting or standing working position.

Observation protocols were used to verify the equal working conditions due to temperature and noise for all days of data acquisition. Furthermore the nonworking times were analyzed.

The 23 subjects were divided in two age groups as Table 1 shows.

Statistical analyses of the data were made with the SPSS® Predictive Analytics Software (PASW® Statistics 18.0.0).

The t-test was used to find significant differences and correlation coefficients (r) were calculated. In addition, partial correlation Pearson chi-square-test and Fisher´s exact test was employed. All p values are reported as significant at less than 0.05.

3. Results

Subjects who were accredited to take part at the study had no significant difference referring to BMI (body mass index) (see Table 1). The work ability index (WAI) of younger and older women is "good" (good = 37-43 points; [16]) with no significant difference within the groups (see Table 1). The younger

group (mean = 1.585) achieved a significantly higher value of PPI (pulse-performance-index) than the older group (mean = 1.270; $t(21) = 2.450$, $p = 0.023$) (see Table 1).
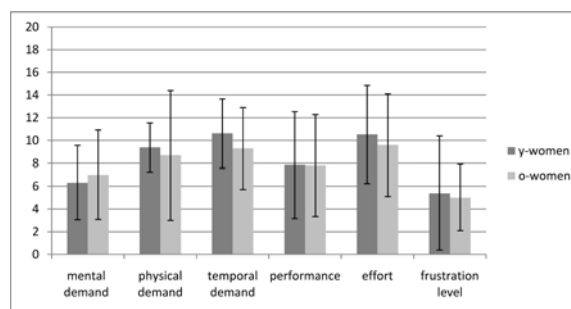

Fig. 2 Results of Task Load Index (TLX)

Both the score of the TLX and the single items showed no significant differences between the younger and the older group (see Fig. 2). For all subjects temporal demand (mean = 10.04) was perceived higher than mental demand (mean = 6.61; $t(22) = -3.875$, $p = 0.001$). Physical demand (mean = 9.09) was also experienced higher than mental demand (mean = 6.61; $t(22) = -3.007$, $p = 0.006$).
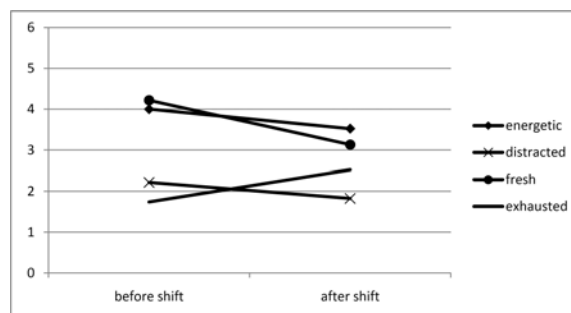

Fig. 3 Significant strain ratings of subjects before and after shift

Altogether there was a significant difference between all subjects in strain-ratings before and after shift. Subjects assessed their mood within a range from 1 (not at all) to 6 (very). All subjects felt less energetic ($t(22) = 2.307$, $p = 0.031$), less distracted ($t(22) = 2.398$, $p = 0.025$), less fresh ($t(22) = 4.204$, $p < 0.01$) and more exhausted ($t(22) = -2.657$, $p = 0.014$) after the shift (see Fig. 3).

Two out of 12 items of the strain-ratings displayed a significant difference due to age. The older women stated to be more unsure (mean = 1.80) at begin of the shift than did the younger women (mean = 1.15; $t(21) = -2.095$, $p = 0.048$). While the energy level

before and after the shift remained stable for older women, it declined for the younger. After the shift the younger women (mean = 3.08) felt less energy than did the older women (mean = 4.10; t(21) = -2.640, p = 0.015) (see Fig. 4).
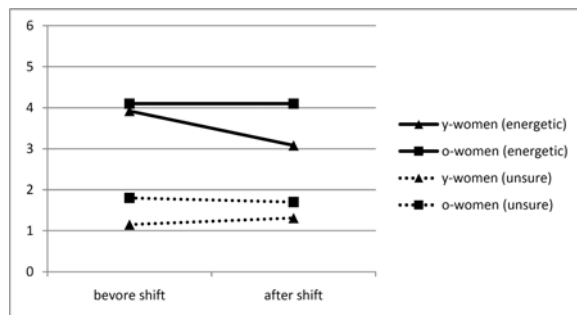

Fig. 4 Significant strain ratings of younger and older women before and after shift

Most of the subjects (75.04 %) were sitting during the measurement, but there was no difference in sitting or standing between younger and older women (Fisher´s exact test: p = 0.325). Depending on age there was no significant difference in the mode of operation (sequence of assembly, arrangement of load carriers, storing).

The following results reflect the findings regarding average assembly time of period No. 1. The younger women (mean = 14.940s) needed in comparison less average time for assembly than the older women (mean = 17.040s; t(472.026) = -9.278, p < 0.01) (see Fig. 5). On closer examination of the younger group there is a correlation between average assembly times and nonworking times (r = -0.622, p = 0.023).

There is a correlation between age and average assembly time (r = 0.592, p < 0.01) and age and MCTQ (r = -0.52, p = 0.011). A partial correlation of age and average assembly time with the covariate MCTQ showed a significant correlation (r = 0.567, p < 0.01). Fishers exact test was used to show the distribution of chronotypes between younger and older women (p = 0.286). There is no correlation between average assembly time and WAI, BMI, arm discomfort und shoulder discomfort but there is a correlation between hand discomfort and average assembly time (r = 0.532, p < 0.01). Fisher´s exact test (p = 0.214) was used to state the equal distribution of hand discomfort of younger and older women.

4. Discussion

The aim of this field study was to investigate women of different age who are quite similar in their preposition but only differ in age. The results of WAI, TLX and BMI show, the investigated subjects are a homogeneous group in this regard. The work ability is "good" for all subjects and does not differ significantly between both age groups. Results of the TLX indicate the similar subjective appraisement of work and the results of BMI show subjects` similar physical conditions. Despite the differences in PPI, a PPI > 1 is still good for both groups [27].

The results of strain ratings before and after shift show the influence of work to all subjects. Independent of age they felt less energetic, less distracted, less fresh and more exhausted after work. The older women´s constant energy level before and after the shift may result from the slower working speed. The younger women were more than 12 % faster than the older ones in the average assembly time and they felt less energetic after the shift. As the results show, there is an age dependent difference in average assembly times between younger an older women. The differences in assembly time could be ascribed to the fact that there was no time pressure in the assembly through work cycle, so the women were free in determining their individual working speed. The correlation between average assembly time and nonworking times among the younger subjects indicate that they use their fast working speed to acquire additional breaks of work. Due to assembly times detailed analysis is under examination. Heart frequency was used as an indicator for the objective strain, because it could be registered without influencing the working process. This condition was an essential requirement to conduct the field study. Analysis is still in progress.

It is critically noted that the sample with 23 women is relatively small and the distribution of age is not ideal. The age of the women was distributed unequally with the majority of the women being in their mid-fourties. Therefore, no young women < 27 years could be investigated.

In conclusion, more additional data to consolidate the findings and the complex interrelations of age and work are necessary.

Table 1
Mean values (± SD) of data gained in the medical examination for younger (y) and older (o) women

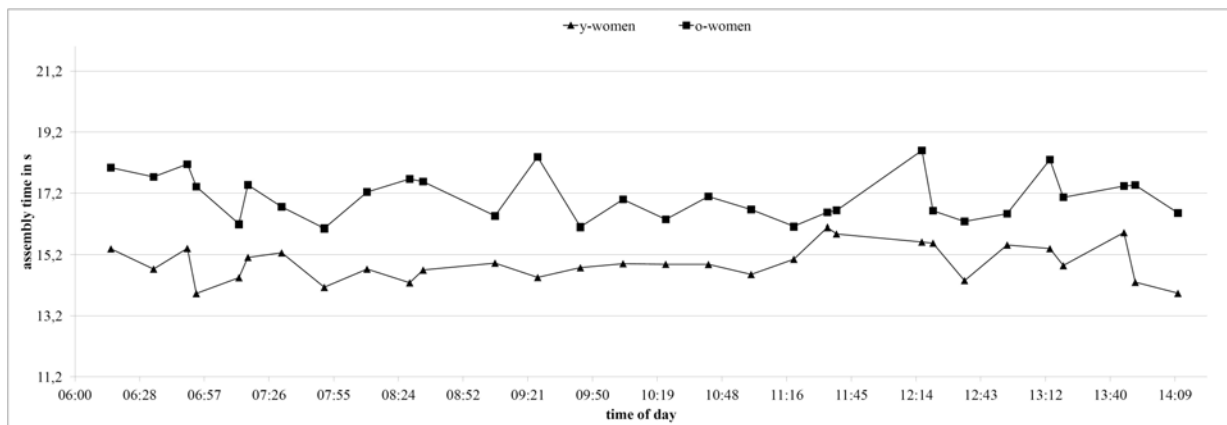|	n	Age (years)	Weight (kg)	Hight (m)	BMI (kg/m^2)	WAI (points)	PPI
Y-Women	13	39.7 ± 4.44	67.8 ± 10.83	1.672 ± 0.0572	24.3 ± 4.23	37.5 ± 5.43	1.58 ± 0.30
O-Women	10	49.4 ± 5.32	75.1 ± 15.33	1.651 ± 0.0420	27.5 ± 5.20	38.6 ± 4.99	1.27 ± 0.31

Fig. 5 Different average assembly times of younger and older women

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