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CHANGEABILITY TRAINING FOR EMPLOYEES IN MANUAL ASSEMBLY

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ABSTRACT

Changeability is a success factor for companies as they are facing increasing market dynamics such as shorter product life cycles, fluctuating demands and higher product complexity [1].

For this reason a training concept to improve changeability of employees in manual assembly has been developed. Focus of this training is the routines that are used during manual assembly processes.

The elements within the training concept are derived from methods used for changeability training in gymnastics. The plausibility of this transfer from gymnastics to manual assembly has been shown by a detailed comparison of the two domains.

To demonstrate the effectiveness of the changeability training an assembly simulation has been applied.

In order to easily use the training for companies, it is build up in a scalable way so that it can be adapted without difficulty to company specific needs and with respect to the conditions of employees and the organisation.

1. PURPUSE

The purpose of this paper is to present the changeability training that has been developed for employees in manual assembly, to explain the approach that has been used during the research as well as to show the results that have been achieved.

2. CURRENT SITUATION AND NEED FOR RESEARCH

Most industries are facing increasing market dynamics such as shorter product life cycles, fluctuating demands and at the same time higher product complexity [1]. To be competitive under these conditions it is necessary to establish changeability as a systematic and lasting strategy in all areas of the company: technology, organization and employees [2].
Most research activities focus on increasing changeability in the area of technology and organization, whereas from company side the training of employees on changeability is urgently needed [3].

3. OBJECTIVE AND APPROACH OF THIS RESEARCH

The focus of this research is to develop a training concept to improve changeability of employees in manual assembly areas.

Changeability of employees means to qualify them for a widely diversified field of activities and to enable them to manage the challenges of changes on their own.

Carrying out movements is the main activity in the manual assembly. For this reason the following study is based on transforming methods known in gymnastics to the manual assembly process.

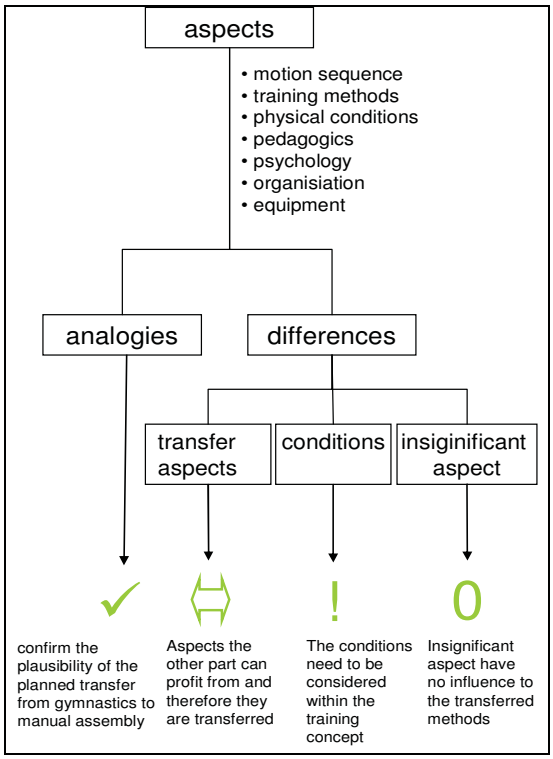

Illustration 1: Correlation between gymnastics and manual assembly

In order to check the plausibility of the proposed transfer from training methods in gymnastics to manual assembly, the analogies and the differences within various aspects (e.g. motion sequence, training methods, pedagogic, and psychology) are analyzed, see illustration 1.

The identified analogies confirm the plausibility of the planned transfer from gymnastics to manual assembly. Most relevant analogies for this research are the importance for both domains to synchronize movements and transfer to automatic execution of the tasks quickly. Both are valid for movements concerning the whole body, like in gymnastics, and for part body movements like in manual assembly.

Derived from the identified differences between gymnastics and assembly are the transfer aspects, the conditions and the insignificant aspects that can be neglected in respect to this research.

The transfer aspects contain procedures and methods from gymnastics (e.g. flexibility and learning procedures) that increase changeability so that manual assembly can profit.

Among the conditions is for example a feasible duration of the training. All identified conditions need to be considered within the training concept.

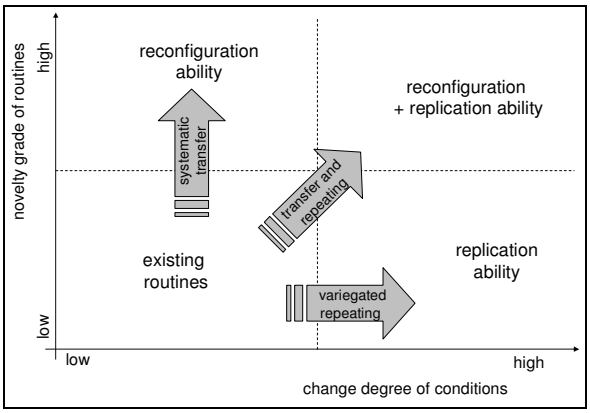

Illustration 2: The two aspects of changeability

One of the insignificant aspects is the different age of an average gymnast compared to an employee in assembly. This is insignificant because the method itself is transferred independently of age.

As a result of all analogies and differences the training methods from gymnastics that train and increase flexibility as well as the motor learning process can be used to develop a changeability-training for employees in manual assembly.

The elements of the changeability-training are divided in two dynamic abilities. These are replication and reconfiguration [4].

Replication ability is repeating routines in a stable way while conditions are variegating; reconfiguration ability is transferring existing routines to new situations. Employees need to be trained in both abilities, see illustration 2.

4. RESULTS

The results are divided into three levels: the training elements as such, the exemplary application of selected training elements and the scalable training concept as a consolidation of the full research work.

4.1. Training elements

Nineteen elements for training replication and reconfiguration ability in manual assembly have been developed by transforming, adopting and converting existing training methods that are known from gymnastics.

4.1.1. Training elements for replication

As replication ability means keeping performance of routines stable while conditions are changing, employees in manual assembly must be able to perform a fast target/actual-comparison within their movements and adjust

accordingly. To manage this successfully a good neuromuscular differentiability is needed.

To train neuromuscular differentiability in gymnastics, three training approaches are used: the senso-motoric training which improves the afferent (sensory) differentiability, the intra- and intermuscular coordination training to increase the efferent (motor) differentiability and the differential training which incorporates shares out of the first two. [5]

Based on these three approaches the following nine training elements are created to train neuromuscular differentiability in manual assembly and therefore replication ability.

The special feature of each of the nine training elements is summarized below in one sentence. Only the training elements (1) Changing Conditions and (5) Over-dimensioning are described on a more detailed level as they are referred to later.

(1) Changing Conditions:
Mastered movements (routines) are trained under varying basic conditions: for example an increased noise level, changes in the illumination, a different material provision or modified components. By changing several basic conditions during the training, the employee learns to adapt his/her actions quickly to this varying environment.

(2) Training Competition:
Movements are carried out in competition-like situations such as time pressure or observations.

(3) Slow-motion:
Routines are trained on different levels of reduced speed.

(4) Worst Case Scenario:
Solution strategies to avoid severe situations are used.

(5) Over-dimensioning:
Routines are trained on a higher level than which is actually needed. This can be achieved by either an increased difficulty like a shortening of cycle time or by amplification which means for example adding an extra task to the routines.

(6) Conscious Failure Correction:
Routines are aware executed and respective cause-related corrections are done.

(7) Ideomotoric Training:
The trainee carries out movements only in his/her imagination.

(8) Individuality:
Permanently varying and individually set target corridors are used to carry out the movements and by this to learn quickly the respective individual optimum.

(9) Dynamics:
The degree of difficulty for the trained movements is increased permanently and continuously but always with regards to the individual condition and performance.

4.1.2. Training elements for reconfiguration
Reconfiguration means that employees in manual assembly are able to transfer already learnt routines to new situations. To manage this successfully it is important to consider a positive transferability of the movements and to be efficient in the motor learning process.

As a result the employee is able to use his abilities and flexibly to perfectly adapt to a new situation. An already available movement, e.g. bi-manual-work can then be transferred to different cases (e.g. screwing, gripping).
The positive transferability means that the employee must be enabled to be aware which available routine he has to apply. Interference must be avoided so that already existing movements have no negative influence to the new motions. In the next step these existing routines have to be applied to the new situation by motor learning. There are three steps until gaining the variable availability of the movements, first step is to get gross motor skills, the second is the fine coordination and the third the final step is the autonomous phase. [6]

Training elements for the final step of the motor learning process are already described within the replication training elements as the focus therefore is to train neuromuscular differentiability.

The following ten training elements are identified to train the motor learning and the transferability. They are briefly described in one sentence and only the training element (16) Additional Information, (18) Verbalizing and Self Order and (19) Mental Imagery of Movement is explained in more detail as it is referred to it later.

(10) Individual Conditions:
The learning methods and steps are adjusted to the personal conditions of the trainee.

(11) Learning with Sensory Perception:
The new movement is verbally or visually instructed.

(12) Standardized Convenient Conditions:
The conditions and the new movement itself are kept as standardized as possible.

(13) Active Support:
The trainee gets assistance while performing the motion, e.g. is kept in the movement by the trainer.

(14) Learning Stepwise:
The whole movement is done active by the trainee even in an imperfect way.

(15) Repeating:
The motion is consciously replicated so that there is a "repeat without repeat".

(16) Additional Information:
There are acoustics, rhythmic or visual information during the movement, e.g. clapping hands, visual marks. This helps the trainee to learn the right moment to initialise the motion.

(17) Verbal Advice:
The trainer explains the moment when to initiate the movement before performing the movement as exact as possible and corrects him straight after performing.

(18) Verbalising and Self Order:
The trainee describes its mental imagery straight after performing. Furthermore the trainee gives orders to himself during performing to initiate movements, e.g. stand, and keep the arms straight.

(19) Mental Imagery of Movement:
The acting person describes the image of the movement from memory. In the beginning it is viewed from an external perspective, later on after exercising an internal perspective is formed. This ability is trained by various methods, e.g. giving orders during the movement, showing the learners how they performed by video analysis.

4.2. Exemplary application

4.2.1. Realization of the exemplary application
To demonstrate the effectiveness of the changeability training elements an assembly simulation is used to train and test the level of replication and reconfiguration. The simulation is based on a lego® model, see illustration 3, which is used to exemplarily apply five training elements: (1) Changing Conditions, (5) Over-dimensioning, (16) Additional Information (18) Verbalising and Self Order and (19) Mental Imagery of Movement.

Training and test include two routines that are an important part of an efficient and ergonomic assembly.

The first routine is bi-manual-work, an aspect of ergonomics and kinematics.

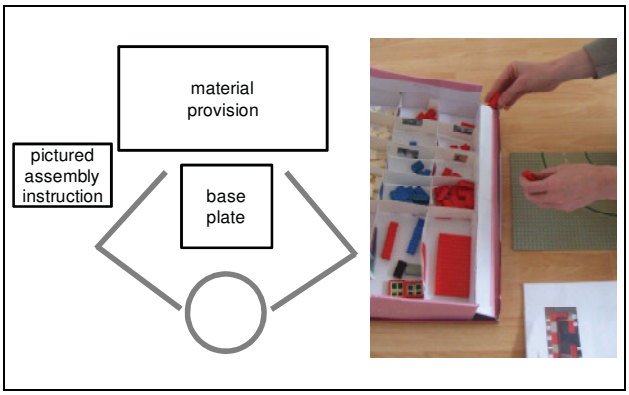

Illustration 3: Assembly simulation (schematic and exemplary)

The second routine is to perceive assembly sequences, an aspect to master the assembly process.

Training and test are performed by two groups of test persons that are compared in changeability level. The first group which is the training group is trained according the changeability training elements. The second group which is the reference group is trained according to "*REFA four step method*", in the conventional way [7]. In both groups age, sex and motion experience is equally distributed.

The training consists out of three steps, twenty minutes each, with a subsequent performance test after each step. In the performance test the time needed to assemble the lego® model and the quality of the routines are measured.

The first step of the training is identical to both groups and is performed according the established *"REFA four step method"*. The four steps of REFA are: explanation by trainer, demonstration by trainer, training with trainer support, self-contained training [7]. The following performance test is used as a reference performance of each test person. The delta deviation to the first performance test is used to show the success of the second and third training steps.

The second and third training step has a different content for the two groups but the same time duration. The reference group trains self-contained according step 4 of the REFA training process and with the original lego® model which is comparable to the first training step.

The training group practises replication ability in the second training step and reconfiguration ability in the third step.

For the replication training of the second step the two routines bi-manual-work and perceive assembly sequences, are trained according the training elements (1) Changing Conditions and (5) Over-dimensioning. The corresponding exercises are done offline which means by tasks independent from the original lego® model but still using lego® elements. This is important to concentrate on the changeability aspect in general and not being dependant on a specific model. In detail, the training exercises are for example that within a limited time and having a completely unsorted material provision, a base plate has to be bi-manually and symmetrically filled with as many elements as possible.

The subsequent performance test for replication ability (second performance test) is different to the reference test in the following contents: partly unsorted material, changes in the model itself and questions to be answered during the assembly. The tasks in the performance test are not identical to the training tasks. This ensures that only the changeability level is tested and not the level of improvement due to simple repetition.

In the third and last training step the training group practises reconfiguration ability by transferring the two routines, bi-manual-work and perceive assembly sequences to other movements. The training elements (16) Additional Information, (18) Verbalising and Self Order and (19) Mental Imagery of Movement are exercised offline as in the second step. The training consists of building asymmetric models bi-manually according an assembly instruction while verbally describing the doing and being filmed during performing.

The succeeding performance test for reconfiguration ability (third performance test) consists of the following different tasks compared to the reference and training model: changes in the model itself, the model is not symmetric anymore, the left and the right hands have to handle different elements at the same time and both hands have to work crosswise.

4.2.2. Results of the exemplary application

The results of the second performance test (for replication ability) and of the third performance test (for reconfiguration ability) of the two groups are evaluated regarding the measured time to build the model and the quality of the routines which is measured in failure rates.

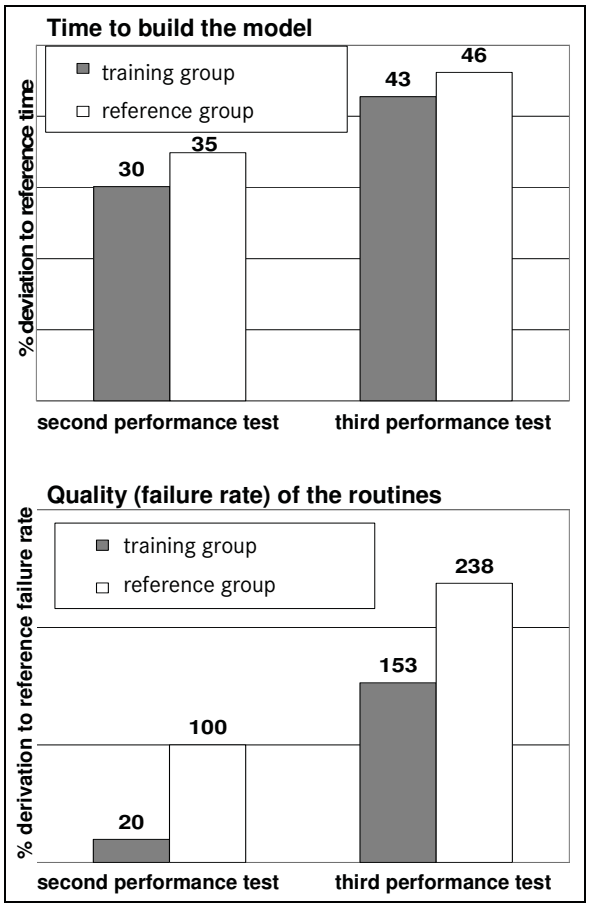

Illustration 4: results of the exemplary application

Both criteria are compared to the reference performance that has been measured after the first training step, see illustration 4.

Looking at the time to build the model the training group is slightly faster than the reference group in both performance tests.

Comparing the quality of the routines of the two groups the difference can clearly be seen in both performance tests. In the second performance test the reference group is causing in average 100% higher failure rate compared to its reference failure rate. In contrast, the failure rate of the training group is only 20% higher compared to its reference failure rate. The third performance test shows as well that the reference group is causing in average a much higher failure rate (238%) compared to the training group (153%).The results of this exemplary application strongly suggest that the chosen training elements have a positive effect on changeability in manual assembly.

4.3. Scalable training concept

A scalable training concept, in which all training elements have been incorporated, has been

developed. The conditions as above identified for a successful transfer of the training methods from gymnastics are respected in the concept. Additionally the concept takes into account that time and resources for training are limited in industry. This is achieved by the developed navigation aid that ensures the right choice and design to the exact needs of the company.

Step one in the navigation aid is to determine the process driver why changeability is needed for the respective company and to identify if the focus is more on the replication or more on the reconfiguration side. This is done by a questionnaire. Depending on the result the corresponding training elements either for replication or reconfiguration or both are chosen in the next step.

In step two the motion and action patterns such as assembly sequence, testing and material handling, identify the required training elements. The reason is that not every element is recommended for each motion and action pattern. For example for the motion pattern of bi-manual-work only six are recommended for training replication ability and six for training reconfiguration out of the nineteen developed elements.

Step three of the navigation aid is to consider the individual degree of mental imagery of the trained person. The level is evaluated by a multiple choice questionnaire. Depending on the results the training element (19) Mental Imagery of Movements and (7) Ideomotoric Training can be used with or without additional training elements for preparation.

In step four of the navigation aid advices are given how to design each element according to training element (10) Individual Conditions of the employees (e.g. the physical, motional, intellectual or psychological ability) and the general framework of the company (e.g. availability of trainers or on-site aspects).

Step five helps to indicate the main sources of errors for each of the training elements and advises how to correct them. The sources of errors are closely linked to the training element (6) Conscious Failure Correction and to the above mentioned training element (10) Individual Conditions because they may cause failures if they are not taken adequately into account.

The navigation aid and its five steps are visualized in illustration 5.

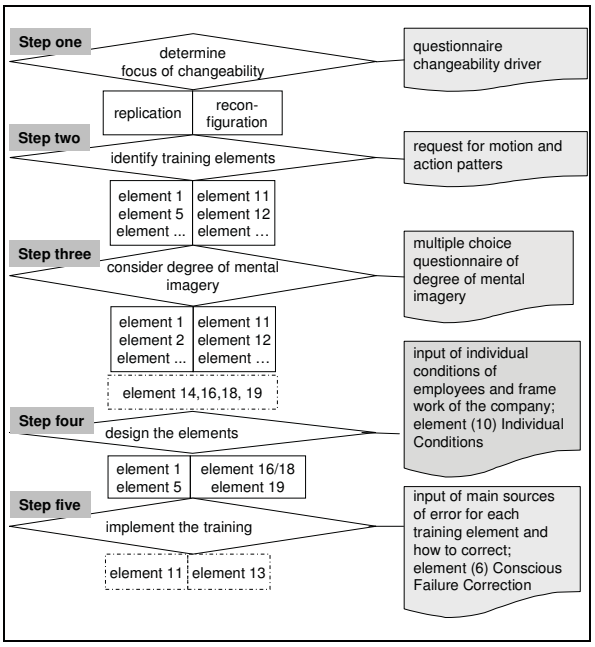

Illustration 5: navigation aid for the scalable training concept

5. CONCLUSION

To improve changeability of employees in manual assembly, respective training elements have successfully been developed by transferring training methods from gymnastics to manual assembly.

The plausibility of this transfer is proved by a detailed investigation.

The effectiveness of the training elements is demonstrated in an exemplary application.

All training elements are integrated into a training concept. This concept can be implemented by different kinds of companies because it is developed in a way that suitable training elements can be chosen according to company specific needs and strategies.

6. REFERENCES

[1] P. Nyhuis, G. Reinhart, E.Abele, Wandlungsfähige Produktionssysteme - Heute die Industrie von morgen gestalten, Bundesministerium für Bildung und Forschung, 2008

[2] H.-P. Wiendahl, Veränderungsfähigkeit von Produktionsunternehmen, ZWF, 2009

[3] P. Nyhuis, P. Fronia, et.al., Wandlungsfähige Produktionssysteme: Ergebnis Vorstudie, Werkstatttechnik online, Jahrgang 99 H.4, 2009

[4] E. Zahn, Wandlungsfähige Produktionsstrukturen - Das Stuttgarter Unternehmensmodell, Universität Stuttgart, 2006

[5] F. Bessi at al, Materialien für die Trainerausbildung im Gerätturnen (2. Lizenzstufe), Eigenverlag, 2007

[6] K. Meinel, G. Schnabel, Bewegungslehre Sportmotorik – Abriss einer Theorie der sportlichen Motorik unter pädagogischem Aspekt, Meyer&Meyer Verlag, 2007

[7] REFA, Methodenlehre der Betriebsorganisation Arbeitspädagogik, REFA Verband für Arbeitsstudien und Betriebsorganisation, 3. Auflage München: Hanser, 1991

[8] P. Kurtz, Department of Work Science, Faculty of Mechanical Engineering, Ilmenau University of Technology