Predictors of the discrepancy between calendar and biological age

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Background The rate of ageing can differ considerably between individuals. This might result in major differences between calendar age (CA) and biological age (BA).

Aims To identify work- and health-related predictors of the discrepancy between CA and BA.

Methods The sample analysed in this study consisted of 371 subjects of different occupational groups (teachers, office workers, nursery school teachers and managers). BA was measured with the vitality measuring station, which recorded 45 vitality indicators of physical, mental and social functions.

Work ability index, effort–reward imbalance and relaxation inability were measured to determine work- and health-related predictors.

Results The greatest discrepancy between CA and BA (9 years) was found for the subgroup of managers, followed by female teachers (5 years). Managers showed also the best results in work ability, the effort–reward balance and relaxation ability.

By means of multiple regression analysis, particularly mental attitudes and resources towards work, occupational reward and the body fat percentage were identified as relevant predictors for the discrepancy between CA and BA.

Conclusions Our study indicates that not only health- but also work-related factors are associated with vitality and BA of employees. We assume that measures focused on promoting of health (healthy diet and physical activities) and improving working conditions (e.g. job satisfaction and social support and stress prevention) may also affect the ageing process positively.

Key words Biological age; calendar age; health- and work-related predictors; vitality; work ability.

Introduction

There is no doubt that the demographic development will affect the age structure of workers in the workplace. All forecasts assume a rise in the average age of employees [1]. Since ageing is associated with changes in functional capacity, suitable measures for maintaining and promoting health and work ability of ageing workers will be of increasing importance for occupational safety and health.

Biological age (BA) that refers to the human functional capacity can differ considerably between individuals [2–4] of the same calendar age (CA). Individuals might be healthier, more vital and biologically younger than might be expected from their CA and vice versa. On the one hand, genetic ‘intrinsic’ factors that can hardly be influenced contribute to the interindividual differences; on the other hand, extrinsic factors act on the ageing process, which can affect a person’s functional capacity and its changes with age both positively and negatively. Within the conceptual framework of ‘successful ageing’ [5,6], the effectiveness of extrinsic factors that counteract the intrinsic age-accelerating factors is assumed. Losses in function with advancing age can be avoided or at least restricted [7] by protective extrinsic factors.

The influence of work-related factors on the ageing process has hardly been studied to date. In general, there is no doubt that a high level of engagement with life including productive engagement in occupation [8,9] is a strong predictor of successful ageing. Barnes-Farrell and Pietrowski [10] studied the relation between work stress and worker’s self-perceptions of the ageing process. The reported presence of stressors and the extent of strain were positively correlated with feeling older than one’s CA. Hacker [11] postulated that poor working conditions might induce ‘work-induced ageing’, e.g. working conditions that impair physical and mental functionality can lead to premature ageing.
There are different approaches to evaluate the rate of ageing on basis of BA measurements [4,12]. BA cannot be measured directly but merely approximated using certain vitality and age indicators [4].

Data of BA analysed in this study were obtained using the so-called vitality measuring station (VMS) [13]. This methodological approach is based on the ‘concept of vitality’ [13], which defines the construct of vitality as an individual’s age-typical whole-organism functionality in their unity of physical, mental and social efficiency. Efficiency in the different functional domains was determined on basis of 45 vitality indicators implemented in the VMS approach.

The aim of this study was to examine the discrepancy between CA and BA in employees of different occupational groups, which were assumed to differ in work ability and other work-related factors. We were interested in analysing the BA–CA discrepancy in relation to work- and health-related factors. Furthermore, we tested which of these factors are relevant predictors for the discrepancy between CA and BA. We hypothesized that protective work- and health-related indicators are related to BA that is lower than CA, i.e. to positive discrepancies between CA and BA.

**Methods**

Data for this analysis were pooled from three studies [14–18] conducted with identical questionnaires [relaxation inability (RI), Work ability index (WAI) and effort–reward imbalance (ERI)] and measurements (VMS). The sample consisted of female teachers [17,18], female office workers [15], female nursery school teachers [14], male teachers [15,18] and male managers [16].

Except for the nursery teachers, all employees worked >35 h/week. Working 35 h/week is equivalent to working full time in Germany. They work an average of 40.3 h/week with only marginal differences between different groups [19]. The higher proportion of nursery teachers working <35 h/week was explained by the fact that a relatively high percentage of this professional group (>50%) work part time [20].

In our study, discrepancy between CA and BA as dependent variable is defined by taking CA minus BA. BA was measured with the VMS. This inventory comprises 45 vitality indicators to assess functionality in the cardio-pulmonary system (blood pressure, pulse at rest and after workload and fitness index after submaximal workload), the musculoskeletal system (muscular strength, speed and coordination capabilities) and of the sense organs (visual/auditory acuity and visual/auditory reaction time). Furthermore, psychological and mental functions (verbal/cognitive response, concentration, flexibility, strategy building and memory capacity), physical and psychological complaints and social factors (obligations and leisure time, behaviour and stress and social competence) were estimated by means of VMS. Values of each indicator were standardized to values for a defined reference population and summarized in a value for BA [12,13].

Health-and work-related determinants were analysed by means of the RI questionnaire [21], the WAI [22–24] and the ERI [25,26] questionnaire. Furthermore, body mass index (BMI) and body composition (body fat and active cell mass) were measured as relevant health-related factors.

RI was examined using the corresponding subscale from the standardized RI questionnaire [21]. The RI index consists of six items referring to inability to relax from work. The score for RI ranges from 6 to 24 (high RI values indicate a high RI and low values a high relaxation ability). The general cut-off for ‘noticeable’ values is 19 and for ‘very noticeable’ values is 21.

The WAI describes how well an employee is capable to do his job [24]. It is based on the concept of work ability [22–24], which considers that work ability is determined by the interaction between specific work demands, individual health conditions and mental resources. The WAI questionnaire consists of seven subscales referring to different aspects of work ability (WAI 1—current work ability compared with the life time best, WAI 2—work ability in relation to the physical and mental demands at work, WAI 3—current number of diseases or injuries diagnosed by a doctor, WAI 4—subjective estimation of work ability impairment due to diseases, WAI 5—sick leave during the past 12 months, WAI 6—personal prognosis of work ability in the next 2 years and WAI 7—mental attitudes and resources towards work).

The cumulative index of WAI ranges from 7 to 49 points. It is divided into the following categories: poor (7–27 points), moderate (28–36 points), good (37–43 points) and excellent (44–49 points) work ability.

The ERI at work was measured by the short version of ERI questionnaire with 23 items [25,26]. The subscale ‘effort’ (range: 6–30, high values indicate a high effort at work) refers to the perceived time pressure, work interruptions and disturbances, responsibilities at work, overtime, etc. The subscale ‘reward’ (range: 11–55, high values indicate a high level of occupational reward) measures satisfaction with financial- and status-related aspects, esteem rewards and job security. If the ratio between effort and reward at work is higher than 1 (high effort and low occupational reward), health risks can be expected.

Descriptive analyses encompass means and standard deviations for quantitative measurements and percentages for categorical variables. For ordinal and non-normally distributed variables, medians are presented. Normal distribution was assessed by inspecting skewness and kurtosis of the respective residuals. Skewness and kurtosis should lie between −1 and 1 to accept normal distribution. Comparisons between subgroups were
conducted using analysis of variance (ANOVA) with subsequent pairwise comparisons (Tukey’s B) or chi-square tests according to the scaling of the target variable. To determine potential work- and health-related predictors and to weigh positive and negative influences, bivariate correlation and regression analyses were calculated as a first step and these were then extended to cover multiple regression models. Only such predictors were involved in the models, which are not in the VMS inventory for BA measurement; in total, 23 potential predictors were analysed. The level of significance was 0.05 (two sided) for all statistical tests. The subgroup comparisons of Model 1 were corrected for multiplicity using Tukey’s B method. However, no adjustment for multiplicity on the 5% level using the Bonferroni correction.

All analyses were done using commercially available software (SPSS for Windows, release 15.0).

Results

The sample consisted of 371 subjects belonging to the following five subgroups: female teachers (n = 100) [17,18], female office workers (n = 60) [15], female nursery school teachers (n = 65) [14], male teachers (n = 99) [15,18] and male managers (n = 47) [16]. Participation rates differed among the five subgroups (female teachers, 58%; office workers, 57%; nursery school teachers, 86%; male teachers, 28% and managers, 70%).

The subjects were aged between 20 and 64 years (mean age: 45.6 years). The majority of subjects were married (80%). Education and vocational training of the groups differed in the following ways: all female teachers completed high school, followed by 81% of the group of managers and 78% of male teachers. The majority of office workers (67%) and nursery school teachers (91%) completed secondary school. A university education was completed by 100% of female teachers, 77% of male teachers and 49% of managers. A vocational training was completed by 75% of office workers and 100% of nursery school teachers.

As seen in Figure 1, the highest discrepancy between CA and BA (9 years) was established for the subgroup of management personnel, followed by the subgroup of female teachers (5 years), while for the subgroups of male teachers, nursery school teachers and office workers, no significant discrepancies between CA and BA were found.

The scatter plots shown in Figure 1 (lower graph) emphasize the high degree of interindividual differences with respect to BA for persons of the same CA. Dots below the reference line (BA = CA) represent subjects who are biologically younger. Dots above the reference line represent biologically older subjects. It is obvious that almost all dots representing the group of managers are located below the reference line supporting the high level of vitality in this subgroup.

Furthermore, they showed the lowest number of diseases and the lowest number of sick leave days (Table 1).

Relaxation ability (measured on basis of RI questionnaire) was also best in the group of managers (mean RI = 10.2). The female teachers had the worst (mean RI = 17.1).

Nevertheless, a high proportion of managers showed health risks as indicated by a high percentage of overweight persons (72%), and 9% were obese (BMI ≥ 30 kg/m²), which is a predictor for cardiovascular diseases.

The proportion of smokers was highest in the group of nursery school teachers and lowest in the group of female teachers.

Work ability was also highest in the group of managers (highest mean WAI score and highest values in the WAI items; Figure 2) with the greatest percentage of persons with excellent work ability (94%) compared to teachers (female: 15% and male: 22%), office workers (30%) and nursery school teachers (26%).

The dimensions effort, reward and the ERI ratio (Table 2) were most favourable for the group of managers (lowest values in the effort subscale and highest values in the reward subscales). The worst values in the dimension reward were found in the group of male teachers.

The multivariate analysis includes three general linear models (Table 3).

Model 1 is equivalent to a one-factorial ANOVA with group as the only factor. The constant in this model equals the average difference between CA and BA for the group of manager personnel. The other parameters represent the difference between the four remaining groups and this group. Managers had the most favourable results, followed by female teachers.

Model 2 explores potential characteristics of subjects, which predict the difference between CA and BA. WAI 7 (mental attitudes and resources towards work), fat mass and reward are significantly associated with the outcome variable. From column 2 of Table 3, we can conclude that an increase of one point of the WAI 7 (mental resources) increases the difference between CA and BA by 1.6 years with a confidence interval between 0.4 and 2.8 years.

Model 3 demonstrates whether the group differences of Model 1 may be explained by the predictors identified in Model 2. In general, the differences between the groups become lower. There are only slight changes for nursery teachers and office workers but relevant changes for both groups of school teachers. Thus, the covariates explain at least in part why teachers have worse results compared to management personnel. The covariates explain to a much lesser degree why office workers and nursery school teachers also showed worse results compared to the management personnel.
In our study, the highest discrepancy between CA and BA was found in the group of managers compared to the other subgroups analysed in this study. BA was considerably below CA with an average ‘gain’ of ~9 years, i.e. the managers examined were biologically substantially younger and more vital than would be expected from their CA. The best vitality status is consistent with the result that this subgroup also exhibited good results in relevant work- and health-related factors.

Managers rated their work ability as the best compared to other subgroups. According to the concept of work ability [22–24], we assumed a good consistency between individual resources and the work demands. This assumption was also supported by the result that managers

**Discussion**

In our study, the highest discrepancy between CA and BA was found in the group of managers compared to the other subgroups analysed in this study. BA was considerably below CA with an average ‘gain’ of ~9 years, i.e. the managers examined were biologically substantially younger and more vital than would be expected from their CA.
showed a good balance between effort and reward, which indicates a relatively low level of work-related stress. Furthermore, managers reported not only few illnesses, few sick leave days and high relaxation ability but also fewer health risk factors, such as being overweight and smoking.

By means of multiple regression analysis, mental attitudes and resources towards work, occupational reward and the body fat mass were identified as relevant predictors for the discrepancy between CA and BA.

As already mentioned, the influence of work in combination with health-related factors on the ageing process

### Table 1. Selected health-related factors for different subgroups

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Teachers (female), n = 100</th>
<th>Office workers (female), n = 60</th>
<th>Nursery school teachers (female), n = 65</th>
<th>Teachers (male), n = 99</th>
<th>Management personnel (male), n = 47</th>
<th>Total, n = 371</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA (years)</td>
<td>44.6 ± 7.7</td>
<td>42.6 ± 8.7</td>
<td>43.9 ± 9.2</td>
<td>47.9 ± 6.4</td>
<td>49.2 ± 7.5</td>
<td>45.6 ± 8.1</td>
</tr>
<tr>
<td>BA (years)</td>
<td>40.6 ± 8.0</td>
<td>44.5 ± 5.3</td>
<td>44.9 ± 8.4</td>
<td>46.0 ± 7.0</td>
<td>40.2 ± 8.2</td>
<td>43.4 ± 7.8</td>
</tr>
<tr>
<td>Illnesses (quantity)</td>
<td>2.2 ± 1.8</td>
<td>2.0 ± 1.7</td>
<td>2.0 ± 1.8</td>
<td>1.6 ± 1.5</td>
<td>1.1 ± 1.2</td>
<td>1.8 ± 1.7</td>
</tr>
<tr>
<td>Sick leave days</td>
<td>≤9</td>
<td>≤9</td>
<td>≤9</td>
<td>≤9</td>
<td>0</td>
<td>≤9</td>
</tr>
<tr>
<td>RI</td>
<td>17.1 ± 3.7</td>
<td>13.5 ± 3.8</td>
<td>14.1 ± 3.1</td>
<td>14.3 ± 3.5</td>
<td>10.2 ± 3.4</td>
<td>14.4 ± 4.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.7 ± 3.4</td>
<td>24.3 ± 3.8</td>
<td>25.0 ± 3.8</td>
<td>26.5 ± 2.8</td>
<td>26.4 ± 2.7</td>
<td>25.1 ± 3.5</td>
</tr>
<tr>
<td>Body fat mass (%)</td>
<td>20</td>
<td>23</td>
<td>23</td>
<td>21</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Overweight</td>
<td>28</td>
<td>38</td>
<td>43</td>
<td>69</td>
<td>72</td>
<td>49</td>
</tr>
<tr>
<td>(BMI ≥ 25 kg/m²; %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker (%)</td>
<td>10</td>
<td>15</td>
<td>23</td>
<td>7</td>
<td>17</td>
<td>13</td>
</tr>
</tbody>
</table>

Entries are means and SDs, percentages, according to the scaling of the variable. Sick leave days were coded as an ordinal scale as ‘no sick leave days’ versus ‘one to nine sick leave days’ versus ‘more than nine sick leave days’. Entries are medians of this scale, not on a scale coding exact number of days.

### Table 2. Effort, reward and ERI ratio for different subgroups

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Teachers (female)</th>
<th>Office workers (female)</th>
<th>Nursery school teachers (female)</th>
<th>Teachers (male)</th>
<th>Management personnel (male)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>17.1 ± 4.3</td>
<td>14.7 ± 3.6</td>
<td>14.2 ± 3.0</td>
<td>14.9 ± 3.6</td>
<td>13.3 ± 3.2</td>
<td>15.1 ± 3.9</td>
</tr>
<tr>
<td>Reward</td>
<td>48.6 ± 5.1</td>
<td>47.5 ± 6.3</td>
<td>51.2 ± 3.9</td>
<td>42.7 ± 7.6</td>
<td>52.5 ± 2.9</td>
<td>47.8 ± 6.6</td>
</tr>
<tr>
<td>Effort–reward ratio</td>
<td>0.7 ± 0.2</td>
<td>0.6 ± 0.2</td>
<td>0.5 ± 0.1</td>
<td>0.7 ± 0.3</td>
<td>0.5 ± 0.1</td>
<td>0.6 ± 0.2</td>
</tr>
</tbody>
</table>

Figure 2. WAI for different subgroups with WAI categories (means and SEs).
Table 3. Predictors of the CA–BA discrepancy

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>9.0</td>
<td>-5.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Teachers (female)–management</td>
<td>-4.05** (-0.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>personnel (male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office workers (female)–management personnel (male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nursery school teachers (female)–management personnel (male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers (male)–management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>personnel (male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat mass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reward</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R</strong>/R<strong>adj.</strong></td>
<td>0.1/0.1***</td>
<td>0.2/0.1***</td>
<td>0.2/0.2***</td>
</tr>
</tbody>
</table>

*P < 0.05, **P < 0.01, ***P < 0.001; n.s., not significant. Entries are unstandardized regression coefficients (within brackets, standardized regression coefficients are given). Additionally, confidence intervals are presented for the unstandardized coefficients. In the last row of the table, the percentage of explained variance is described by adjusted and unadjusted \( R^2 \) values. The \( P \) values in the last row refer to overall tests of the entire model. Model 1: \( P \) values refer to the comparison versus male management personnel; additional significances: teachers (female) are significantly different from office workers, nursery school teachers and teachers (male), \( P < 0.05 \) each; office workers, nursery school teachers and teachers (male) are not different from each other, corrected subgroup comparisons (Tukey’s B). Model 2: \( P \) values refer to the test for beta = 0 (no influence of the covariate on the discrepancy of BA and CA). Model 3: \( P \) values for subgroups refer to the comparison versus male management personnel adjusted for the covariates below; additional significances: teachers (female) versus office workers (female) and nursery school teachers (female), \( P < 0.005 \).

has hardly been studied to date. The application of highly standardized instruments in this study to measure BA as well as RI, WAI and ERI can be regarded as a comprehensive and innovative approach to analyse predictors for the discrepancy between CA and BA. These instruments were applied in all subgroups analysed in this study.

Individual employees who participated in the study benefited from this complex approach because they got valuable and comprehensive information about their level of vitality and related risk factors as well as resources.

However, there are significant limitations on the interpretation of our results in relation to the cross-sectional design and a non-random sampling of different occupational groups. From our experiences, individuals with a high level of vitality are highly motivated to pursue opportunities for diagnostic procedures, resulting in a high participation rate such as in the group of managers. This contrasts with the lower observed participation rate of the ‘less vital’ teachers. Therefore, a correlation between vitality and (self-) selection cannot be excluded. Sampling different groups with different participation rates might introduce significant bias in the analysis of associations if factors relevant for (self-) selection are correlated both with determinants and with dependent variables in the current investigation and hence are classical confounders in the analysis of potentially causal relationships.

However, there is no systematic correlation between participation rate and vitality of participants. For example, both the occupational group with the highest participation rate (nursery school teachers) and that with the lowest participation rate (male teachers) show no differences between CA and BA. In contrast, managers with a lower participation rate than that of nursery school teachers revealed the highest CA–BA discrepancy.

Another weakness is that cross-sectional studies do not control for selection effects over time introduced by a process of migration of selected subjects into an occupation and by a selection of a subgroup of healthy workers remaining in this group. With such cross-sectional data, it is difficult to determine the direction of the effects between occupation and the other variables.

We concede that self-selection of subjects may also bias the strength of predictors in our regression analyses. This may hold especially in Model 3 where we can explain discrepancies between the groups in part by relevant predictors. On the other hand, we did not find significant interactions between the study groups and the predictors; thus, the latter bias may not be crucial.

Because of these possible biases, we have to interpret the results with caution, and we cannot draw final conclusions about the effects of work- and health-related factors on the CA–BA discrepancy.

We found interesting associations between different predictors and discrepancy and between CA and BA discrepancy, which need further clarification on causal relationships. One might hypothesize on the basis of our data that managers in our sample have good resources, which compensate for high workload. For example, they reported high levels of job satisfaction, esteem rewards and social support, a high job security (92% of managers believed...
that their job was not at risk) and high educational qualifications that may act positively during the ageing process.

Causal relationships between work- and health-related predictors and CA–BA discrepancy have to be investigated in longitudinal studies. Our study provides first valuable information about possible association between predictors and CA–BA discrepancy, which can be regarded as a predictor of the rate of ageing. We assume that measures focused on promoting health (healthy diet and physical activities) and improving working conditions (e.g. job satisfaction and social support and stress prevention) may also affect the ageing process positively.

Key points
- This study shows that discrepancy between calendar and biological age is associated with different work- and health-related determinants.
- Protective factors (high work ability, appropriate relation between effort and reward at work and good relaxation ability) are associated with a lower biological age than actual calendar age.
- We assume that measures focused on health promotion and improving working conditions (e.g. job satisfaction and social support and stress prevention) may also affect the ageing process positively.

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Conflicts of interest
None declared.

References


