Safety and Health at Work 11 (2020) 458–465

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Original Article

Influences of Neck and/or Wrist Pain on Hand Grip Strength of Industrial Quality Proofing Workers

Bettina Wollesen [1], Julia Gräf [2,*], Nils Schumacher [2], Gianluca Meyer [2], Matthias Wanstrath [3], Christian Feldhaus [4], Kerstin Luedtke [5], Klaus Mattes [2]

[1] *Department of Psychology and Ergonomics, Biological Psychology and Neuroergonomics, Technical University of Berlin, Berlin, Germany*
[2] *Department of Human Movement Science, University of Hamburg, Hamburg, Germany*
[3] *German Social Accident Insurance for the Health and Welfare Services, Department for Occupational Medicine, Hazardous Substances and Public Health, Hamburg*
[4] *Corporate Safety & Health, Continental AG, Hanover, Germany*
[5] *Department of Medicine, Academic Physiotherapy, Pain and Exercise Research, University of Luebeck, Luebeck, Germany*

ARTICLE INFO

Article history:
Received 6 November 2019
Received in revised form
23 May 2020
Accepted 24 June 2020
Available online 6 July 2020

Keywords:
Carpal tunnel syndrome
Hand grip force
Neck pain

ABSTRACT

Background: The aim of this study was to analyze the interaction between neck and/or wrist pain and hand grip strength (HGS) and to investigate factors (age, sex, neck disorders, and carpal tunnel syndrome) influencing the HGS of industrial quality proofing workers ($N = 145$).

Methods: Standardized questionnaires [Neck Disability Index (NDI), Boston Carpal Tunnel Questionnaire] were used to evaluate existing neck and/or wrist pain. HGS measurements were performed in different wrist positions.

Results: Significant differences between participants with and without neck pain were found in different wrist positions, in neutral wrist position right [without neck pain ($n = 48$) 46.34 (43.39 – 49.30); with neck pain ($n = 97$) 38.46 (36.20 – 40.72), $F_{(1,144)} = 16.82$, $p < 0.001$, $\eta_p^2 = 0.11$] and left [without neck pain 44.06 (41.19 – 46.94); with neck pain 37.36 (35.13 – 39.58), $F_{(1,144)} = 12.70$, $p < 0.001$, $\eta_p^2 = 0.08$]. A significant difference between participants with and without wrist pain was found for neutral wrist position right [without wrist pain ($n = 105$) 42.53 (40.37 – 44.70); with wrist pain ($n = 40$) 37.24 (33.56 – 40.91), $F_{(1,144)} = 6.41$, $p = 0.01$, $\eta_p^2 = 0.04$]. Regression analysis showed significant results especially for steps two (age and weight, NDI) and three (age and weight, NDI, Boston Carpal Tunnel Questionnaire) for neutral position right ($R^2 = 0.355$, $R^2 = 0.357$, respectively).

Conclusion: Neck pain has an impact on HGS but should be evaluated in consideration of age and sex.

1. Introduction

Some industrial work settings, e.g., quality proofing of manufactured products, such as rubber tubes or sealing rings, require manual repetitive handling in various hand positions: neutral position, palmar flexion, dorsal extension, supination, pronation, and combinations of these. Prolonged manual repetitive handling with high frequencies of wrist flexion and extension may lead to pain and functional impairment and an associated reduction in hand grip strength (HGS) [1]. Furthermore, forces, torque requirements, and load distributions, impacting on the employee's posture and especially their wrists, need to be considered, even if the demands vary between tasks [2]. Extensive research by DiDomenico and Nussbaum [3] or Greig and Wells [4], has shown that the greatest capable exertion is achieved, when forces are applied in radial wrist positions. Usually, the tolerance limit for applied forces is set at 75 % of the maximum, for both male and female [5].

Research has shown that HGS is affected by a variety of factors including age, sex, body mass index, occupation, leisure activities, upper-extremity muscular strength, nutritional status, pain, sensory loss, or cognitive decline [6–9]. Furthermore, HGS decrease has been observed as a consequence of numerous pathologies such

* Corresponding author. Department of Human Movement Science, University of Hamburg, Mollerstraße 10, 20148 Hamburg, Germany.
E-mail address: julia.graef@uni-hamburg.de (J. Gräf).

2093-7911/$ – see front matter
https://doi.org/10.1016/j.shaw.2020.06.008

as cervical radiculopathy or carpal tunnel syndrome (CTS). It can also be used to predict disability in the elderly [9–13]. HGS measurements are used to assess upper-limb impairment, treatment progress, and therapy effectiveness because HGS contributes to a person's ability to perform activities of daily living [11,14].

Extensive studies verify HGS to be significantly lower in women, in the nondominant hand and to be negatively correlated with age [15–17]. Age groups above 65 years showed lower HGS than groups aged 20 to 34 years and 35 to 49 years, respectively [7,17,18]. This deterioration of hand function in the elderly is attributed to age-related degenerative structural changes and is often accompanied with pathological conditions such as osteoporosis or rheumatoid arthritis [6,19,20].

Following study results by Russo et al. [21], workers with a lifetime history of manual work, particularly in the forestry industry, and other workers exposed to physically demanding repetitive activities, present significant lower HGS than those who have been employed in nonmanual work. One possible explanation could be the exposition to physical hazards and the repetitive monotonous movements, impacting on the musculoskeletal system and subsequently causing strength deficits [22]. Contradictory results are reported by Josty et al. [23], Anakwe et al. [24] and Werle et al. [25] who found higher HGS in manual workers than in nonmanual work professionals. One additional previous study showed lower mean percentages of HGS differences between the dominant and the nondominant hand [23].

Moreover, HGS is affected by wrist position. Although HGS is usually measured in positions following the standards of the American Society of Hand Therapists [26], other body and wrist positions may lead to divergent results [16,27]. Studies showed strongest HGS in supinated and weakest HGS in pronated wrist positions [28,29]. Furthermore, reduced HGS was reported when measured in flexed and extended wrist positions, compared with HGS in neutral measurement positions, as well as differences between sitting and standing postures [30,31]. The differences were explained by changes in muscle length in flexed and extended positions, resulting in nonmaximal grip force.

A pathology frequently occurring in workers exposed to manual repetitive activities and resulting in lowered HGS is CTS. In this pathological state, lower HGS values occur due to a neurological impairment and the loss of intrinsic muscle strength [32,33]. Especially in nonergonomic wrist positions, pressure on the median nerve is significantly increased in the carpal tunnel, particularly in people with preexisting CTS, which may lead to impaired conduction velocity, consequently resulting in reduced HGS [34–38].

Not only wrist positions influence HGS, research by Amin et al. [39] showed that HGS is significantly lower in flexed, extended, side-bended, or rotated head positions compared with that in neutral positions [39]. Considering manual repetitive precisions tasks, which are often found in the manufacturing industry, many tasks force employees to prolonged and focused visual control. This frequently requires the use of magnifying lenses, which can result in prolonged neck positions while sitting and bending the head to the lens. Nonergonomic neck postures and the subsequently increased neck muscle tension may provoke cervical nerve root compression, as well as neck pain and headaches [40].

Early research by Upton and McComas [41] has shown a possible connection between neck pain, commonly caused by excessive and prolonged neck flexion, and an increased risk for developing symptoms of CTS. High numbers of included patients diagnosed with CTS showed associated symptoms in the arm and neck. Subsequent research addressed this topic and described it as the double-crush phenomenon, in which a simultaneous compression at two or more sites of the peripheral nerve occurs [42–46]. Prolonged and repetitive neck flexion can result in a nerve root irritation in the cervical spine between C5 and C6 causing neck pain (first crush) and potential neurological symptoms along the peripheral nerve (median nerve) [47]. The nerve becomes more vulnerable to develop a secondary damage, commonly caused by compression in the tight carpal canal (secondary crush) and thereby the typical symptoms of CTS.

Especially in the industrial work environment, manual repetitive tasks with nonergonomic wrist and head positions are very common and result in neck, shoulder, and back pain as well as in CTS [48]. These aspects are important economic factors, increasing work absence, loss of productivity and thereby increasing costs. Therefore, work stations need to be adapted to individual physical conditions, especially for women and older employees because these subgroups are most vulnerable to neck, shoulder, lower back, and wrist pain [49–52]. Moreover, concise recommendations for an ergonomic design to protect the hand–arm system at industry workstations are missing.

Therefore, the aim of this study was to answer the following research questions by examining a large group of employees with manual repetitive quality proofing tasks, who work in awkward body positions:

1. Is HGS in different wrist positions (neutral, palmar flexion, dorsal extension, supination, pronation) affected by the presence of neck and/or wrist pain in male and female industrial employees with manual repetitive quality proofing tasks?
2. Which factors (sex, age, neck pain, wrist pain) have the biggest influence on HGS in male and female industrial workers with manual repetitive quality proofing tasks?

We hypothesize that prolonged high force manual repetitive work may lead to increased incidence of neck and/or wrist pain which affects HGS in different wrist positions. Moreover, we suggest an influence of sex and age on HGS.

The study results will help to provide recommendations for ergonomic workstations where manual force is required.

2. Materials and methods

2.1. Ethics statement

Ethical approval for the present study was obtained from the local ethics committee of the University of Hamburg (2018_158). Before the study, all participants gave their written informed consent. The study followed the Declaration of the Helsinki (version of 2013) and was registered at the German Clinical Trials Register (DRKS00015279).

2.2. Participants

Participants were recruited from a German tire manufacturer. A total of 145 employees were included (Table 1). Participation was voluntary, and data were collected anonymously. The male-female

Table 1
Demographic characteristics of participants

Participants	Age [years]	Height [cm]	Mass [kg]
	M (SD)	M (SD)	M (SD)
Female (n = 50)	45.1(10.3)	166.6(5.6)	68.3(11.3)
Male (n = 95)	41.2(11.0)	179.3(7.2)	85.7(14.2)
Total (N = 145)	42.6(10.9)	175.1(9.0)	80.2(15.6)

Note: M = mean; SD = standard deviation; cm = centimeter; kg = kilogram.

ratio is representative of that in the population of industrial workers. Participants were aged between 18 and 59 and routinely performed manual quality proofing tasks, rubber cutting, assembly, or other activities of manual repetitive activity. Their work required frequent and prolonged forward bending in the lumbar, thoracic, and cervical spine as well as frequent wrist flexion and extension. Furthermore, they were partially exposed to high forces to the spinal column and the wrists. For the analyses of the influence of age on HGS, four age groups were identified (18–29/30–39/40–49/50–59 years). Numbers of participants in the respective age groups are presented in Tables 2–5. No other exclusion criteria were set.

2.3. Materials

Before HGS measurements, participants were invited to fill out questionnaires to evaluate the presence of neck pain and CTS. Neck pain was evaluated using the validated German version of the Neck Disability Index (NDI) [53,54]. The intrarater reliability of the NDI has been reported as high with an ICC of 0.92 [54]. The NDI evaluates neck pain symptoms during everyday activities and activity-independent impairments due to problems or injuries in the area of the cervical spine. Based on NDI results, participants were separated into two neck pain groups: values < 10 % were rated as not affected by neck pain [55], whereas values ranging between 10–48% were labelled as neck pain with mild to moderate disability. Higher values were not measured in the current sample.

In addition, the German translation of the Boston Carpal Tunnel Questionnaire (BCTQ) was used to assess the severity of symptoms and the functional status of the hands [56,57]. Amadio et al. [58] showed moderate correlations between HGS and the BCTQ measurements (r = 0.87). Test–retest reliability was reported by Levine et al. [59] with a Pearson's correlation coefficient of r = 0.91 and 0.93 for symptom severity and functional status scales, respectively. BCTQ symptom scores ranging between 2.0–2.5 are considered as beginning symptoms and indicate a high risk for developing CTS [60]. For the purpose of this study, participants scoring ≥2.0 were rated as having wrist pain.

Following the completion of the questionnaires, bilateral HGS measurements in kilogram were performed in a total of five different wrist positions: neutral, palmar flexion, dorsal extension, supination, and pronation with standard handheld force gauges (SAEHAN Professional SH5001). The test–retest reliability in clinical settings is high with r = 0.98 for the right hand and r = 0.99 for the left hand [61].

2.4. Procedure

Participants were visited at their workplace and informed about the aims and the procedures. Afterward, they completed the questionnaires and HGS measurements in different wrist positions were performed. Every measurement was conducted twice with each hand and with one-minute rest between the measurements, following the standard testing guidelines [16]. Measurements took place in sitting position with neutral shoulder and adducted arm positions, 90° flexed elbow, and neutral lower arm positions [16]. Wrist positions were varied in neutral, palmar flexion, dorsal extension, supination, and pronation in a randomized sequence.

2.5. Statistical analysis

Repeated measures ANOVA was used to analyze the main differences in HGS in different wrist positions between the groups

Table 2
HGS and neck pain in male employees, classified by age groups

Handgrip position	Age group 1 (18–29 years; n = 15)		Age group 2 (30–39 years; n = 26)		Age group 3 (40–49 years; n = 29)		Age group 4 (50–59 years; n = 25)	
	NDI <8 % (n = 7)	NDI 10-48 % (n = 8)	NDI <8 % (n = 11)	NDI 10-48 % (n = 15)	NDI <8 %(n = 16)	NDI 10-48 % (n = 13)	NDI <8% (n = 6)	NDI 10-48% (n = 19)
PFr	22.64 (19.60–25.68)	22.69 (20.11–25.26)	24.18 (19.39–28.97)	24.37 (19.48–29.26)	23.75 [21.28-26.22]	24.12 (20.64–27.59)	22.92 (16.84–28.99)	19.84 (17.70–21.99)
PFl	25.21 (23.06–27.36)	23.06 (20.64–25.48)	23.91 (18.59–29.23)	23.83 (20.16–27.51)	24.75 (22.85–26.65)	26.96 (22.64–31.29)	21.83 (18.91–24.76)	21.03 (18.09–23.97)
SUPr	49.64 (41.56–5.73)	50.69 (42.73–58.64)	49.86 (42.93–56.79)	45.20 (39.60–50.81)	50.84 (45.50–56.19)	50.42 (46.87–53.98)	46.00 (37.76–54.34)	41.71 (38.13–45.29)
SUPl	47.64 [41.05–54.24]	45.13 [39.60–50.66]	45.91 [38.98–52.84]	43.10 [37.19–49.01]	47.38 [43.35–51.40]	48.50 [45.32–51.68]	41.50 [34.79–48.21]	41.24 [36.93–45.54]
PROr	38.00 (31.73–44.27)	35.25 (27.06–43.44)	40.00 (34.02–45.98)	35.20 (29.83–40.57)	40.59 (35.22–45.97)	42.69 (39.24–46.15)	37.00 (27.21–46.79)	34.11 (30.89–37.32)
PROl	40.50 (35.32–45.68)	33.06 (26.96–39.16)	39.36 (33.12–45.61)	38.33 (32.29–44.38)	40.72 (36.55–44.89)	41.54 (38.31–44.77)	37.08 (29.21–44.96)	35.34 (32.67–38.01)
DEr	34.57 (32.41–36.73)	35.44 (30.02–40.85)	34.00 (28.70–39.30)	31.73 (26.72–36.75)	34.91 (29.04–40.78)	29.96 (24.94–34.99)	31.17 (24.46–37.88)	29.66 (25.83–33.48)
DEl	30.00 (23.48–36.52)	32.50 (27.66–37.34)	34.23 (29.28–39.18)	30.77 (24.96–36.58)	33.34 (28.18–38.51)	30.69 (26.61–34.77)	29.42 (21.71–37.12)	29.87 (26.20–33.54)
NNr	47.21 [40.36–54.07]	47.44 [39.71–55.16]	52.91 [44.81–61.01]	45.73 [40.52–50.94]	47.97 [43.91–52.03]	48.00 [42.57–53.43]	44.25 [36.63–51.87]	43.24 [40.26–46.58]
NNl	46.36 (41.40–51.31)	42.19 (37.28–47.10)	48.18 (40.20–56.16)	45.60 (39.75–51.45)	47.00 (42.94–51.06)	47.62 (42.30–52.93)	42.83 (36.64–49.03)	42.24 (38.83–45.65)

Note: Values shown are the mean (*M*) and 95 % confidence interval (CI 95 %) in kilogram, NDI=Neck Disability Index, PFr = palmar flexion right, PFl = palmar flexion left, SUPr = supination right, SUPl = supination left, PROr = pronation right, PROl = pronation left, DEr = dorsal extension right, DEl = dorsal extension left, NNr = neutral right, NNl = neutral left.

Table 3
HGS and neck pain in female employees, classified by age groups

Handgrip position	Age group 1 (18-29 years; n = 7)		Age group 2 (30-39 years; n = 7)		Age group 3 (40-49 years; n = 13)		Age group 4 (50-59 years; n = 23)	
	NDI <8 % (n = 1)	NDI 10-48 % (n = 6)	NDI <8 % (n = 2)	NDI 10-48 % (n = 5)	NDI <8 % (n = 4)	NDI 10-48 % (n = 9)	NDI <8 % (n = 1)	NDI 10-48 % (n = 22)
PFr	18.50	13.83 (10.83–16.83)	12.00 (5.65–18.35)	12.10 (8.50–15.70)	16.13 (8.82–23.43)	14.83 (10.41–19.26)	20.50	14.21 (11.83–16.58)
PFl	20.50	14.83 (12.21–7.46)	13.75 (−8.49–35.99)	13.70 (8.74–18.66)	16.63 (10.23–18.41)	15.22 (11.62–18.83)	16.50	14.64 (12.29–16.98)
SUPr	45.00	30.92 (20.82–41.01)	33.25 (11.01–55.49)	25.60 (20.72–30.48)	35.25 (9.25–61.26)	32.22 (25.28–39.17)	24.00	27.93 (25.29–30.59)
SUPl	43.50	31.50 (20.46–42.54)	31.75 (28.57–34.93)	25.10 (21.50–28.70)	32.88 (12.85–52.90)	30.44 (24.13–36.76)	27.00	26.66 (24.12–29.20)
PROr	38.00	23.67 (16.07–31.27)	24.75 (21.57–27.93)	20.50 (17.40–23.60)	30.63 (17.74–43.51)	25.83 (19.59–32.08)	30.00	23.77 (21.05–26.50)
PROl	35.00	24.83 (15.78–33.89)	25.00 (−13.12–63.12)	21.00 (15.59–26.41)	29.75 (17.28–42.22)	26.44 (21.23–31.66)	26.00	23.18 (20.66–25.71)
DEr	24.00	17.33 (12.63–22.03)	26.75 (−20.90–74.40)	18.40 (13.78–23.01)	24.38 (9.71–39.04)	24.39 (17.12–31.67)	23.50	18.77 (15.15–22.40)
DEl	25.50	17.75 (13.07–22.43)	25.75 (−2.84–54.34)	17.40 (13.91–20.90)	20.13 (10.73–29.53)	23.61 (18.76–28.46)	16.00	18.34 (15.38–21.30)
NNr	42.50	30.08 (23.21–36.96)	32.25 (16.37–48.13)	27.30 (21.50–33.10)	36.00 (24.56–37.44)	31.00 (27.42–37.66)	28.00	28.21 (25.68–30.73)
NNl	39.50	30.00 (21.61–38.40)	31.25 (21.72–40.78)	25.00 (21.66–28.34)	31.63 (18.84–44.41)	30.06 (24.93–35.18)	23.00	27.50 (25.15–29.85)

Note: Values shown are the mean (M) and 95 % confidence interval (CI 95 %) in kilogram, NDI=Neck Disability Index, PFr = palmar flexion right, PFl = palmar flexion left, SUPr = supination right, SUPl = supination left, PROr = pronation right, PROl = pronation left, DEr = dorsal extension right, DEl = dorsal extension left, NNr = neutral right, NNl = neutral left.

with and without neck pain disability and between the groups with and without wrist pain for each of the four age groups and for each sex. Bonferroni-corrected post-hoc tests were used for pairwise comparisons. The alpha level was set at 0.05 for all analyzes, and effect sizes were calculated by partial eta square (η_p^2). Spearman's correlation test was used for correlations between age, percentages of the NDI score, scorings of BCTQ and HGS in different wrist positions in male and female groups. A stepwise multiple linear regression analysis was used to analyze the influence of these variables on HGS for each side of the hand. SPSS version 25.0 was used for all statistical analyses.

3. Results

3.1. *Effects of neck pain on hand grip strength in different age groups*

Results for HGS in participants with and without neck pain, separated by age and by sex are shown in Tables 2 and 3. Combining all age groups and sex, significant differences between participants with and without neck pain were found for all wrist positions [palmar flexion right ($F_{(1,144)} = 8.53$, $p < 0.01$, $\eta_p^2 = 0.06$), palmar flexion left ($F_{(1,144)} = 7.32$, $p < 0.01$, $\eta_p^2 = 0.05$), supination right ($F_{(1,144)} = 17.08$, $p < 0.001$, $\eta_p^2 = 0.11$), supination left ($F_{(1,144)} = 13.17$, $p < 0.001$, $\eta_p^2 = 0.08$), pronation right ($F_{(1,144)} = 15.81$, $p < 0.001$, $\eta_p^2 = 0.10$), pronation left ($F_{(1,144)} = 15.03$, $p < 0.001$, $\eta_p^2 = 0.10$), dorsal extension right ($F_{(1,144)} = 14.19$, $p < 0.001$, $\eta_p^2 = 0.09$), dorsal extension left ($F_{(1,144)} = 9.30$, $p < 0.01$, $\eta_p^2 = 0.06$), neutral right ($F_{(1,144)} = 16.82$, $p < 0.001$, $\eta_p^2 = 0.11$), and neutral left ($F_{(1,144)} = 12.70$, $p < 0.001$, $\eta_p^2 = 0.08$)] with higher HGS in participants without neck pain.

Significant differences were found in male employees of age group 1 for pronation left, only ($F_{(1,14)} = 4.78$, $p = 0.05$, $\eta_p^2 = 0.27$), with lower HGS in participants with neck pain. If not separating age groups, no significant differences between participants with and without neck pain were found in male employees.

For female employees, significant differences in HGS between participants with and without neck pain were only found in age group 2 for supination left ($F_{(1,6)} = 9.34$, $p = 0.03$, $\eta_p^2 = 0.65$), dorsal extension left ($F_{(1,6)} = 11.91$, $p = 0.02$, $\eta_p^2 = 0.70$), and neutral left ($F_{(1,6)} = 9.26$, $p = 0.03$, $\eta_p^2 = 0.65$) with lower HGS in participants with neck pain. If not separating age groups, significantly lower

Table 4
HGS and wrist pain in male employees, classified by age groups

Handgrip position	Age group 1 (18–29 years; n = 15)		Age group 2 (30–39 years; n = 26)		Age group 3 (40–49 years; n = 29)		Age group 4 (50–59 years; n = 25)	
	BCTQ <2 (n = 14)	BCTQ ≥2 (n = 1)	BCTQ <2 (n = 19)	BCTQ ≥2 (n = 7)	BCTQ <2 (n = 22)	BCTQ ≥2 (n = 7)	BCTQ <2 (n = 17)	BCTQ ≥2 (n = 8)
PFr	22.86 (21.08–24.64)	20.00	24.82 (21.03–28.61)	22.86 (14.70–31.02)	24.16 (21.69–26.63)	23.14 (20.16–26.12)	21.65 (19.05–24.25)	18.31 (15.19–21.43)
PFl	24.00 (22.34–25.66)	25.00	24.16 (20.45–27.86)	23.07 (18.08–28.06)	25.77 (23.22–28.33)	25.64 (21.11–30.17)	23.00 (20.30–25.71)	17.44 (14.28–20.59)
SUPr	50.32 (45.03–55.62)	48.50	46.82 (42.25–51.38)	48.14 (36.14–60.15)	51.25 (47.36–55.14)	48.78 (42.46–55.11)	45.06 (41.92–48.19)	37.81 (30.71–44.91)
SUPl	45.86 (41.95–49.76)	52.50	44.11 (39.63–48.58)	44.79 (31.95–57.62)	48.48 (45.36–51.32)	46.00 (39.44–52.56)	43.44 (39.94–46.95)	36.75 (28.66–44.84)
PROr	36.29 (31.31–41.26)	40.00	37.61 (33.43–41.77)	36.21 (24.89–47.54)	42.00 (38.08–45.92)	40.07 (33.65–46.49)	37.03 (33.50–40.56)	30.06 (25.03–35.09)
PROl	36.11 (31.78–40.43)	42.50	38.05 (33.73–42.38)	40.71 (28.45–52.98)	41.73 (38.68–44.78)	39.07 (33.26–44.88)	36.74 (33.91–39.56)	33.69 (28.07–39.31)
DEr	35.50 (32.10–37.91)	35.50	32.74 (29.12–36.35)	32.57 (21.95–43.19)	33.50 (28.82–38.18)	30.14 (22.30–37.99)	32.59 (29.30–35.88)	24.56 (18.70–30.42)
DEl	30.89 (27.26–34.53)	37.50	32.47 (28.76–36.19)	31.57 (19.14–44.00)	33.00 (28.90–37.10)	29.50 (24.96–34.04)	31.85 (28.52–35.19)	25.31 (18.94–31.69)
NNr	47.43 (42.56–52.30)	46.00	49.21 (43.89–54.53)	47.57 (36.80–58.34)	48.52 (44.70–52.35)	46.29 (40.32–52.25)	45.56 (42.50–48.62)	39.50 (34.27–44.73)
NNl	43.43 (40.33–46.53)	54.00	46.37 (41.26–51.48)	47.57 (35.74–59.41)	48.43 (44.91–51.96)	43.64 (36.55–50.74)	43.94 (41.21–46.67)	39.06 (32.02–46.12)

Note: Values shown are the mean (M) and 95 % confidence interval (CI 95 %) in kilogram, BCTQ=Boston Carpal Tunnel Questionnaire, PFr = palmar flexion right, PFl = palmar flexion left, SUPr = supination right, SUPl = supination left, PROr = pronation right, PROl = pronation left, DEr = dorsal extension right, DEl = dorsal extension left, NNr = neutral right, NNl = neutral left.

Table 5
HGS and wrist pain in female employees, classified by age groups

Handgrip position	Age group 1 (18-29 years; n = 7)		Age group 2 (30-39 years; n = 7)		Age group 3 (40-49 years; n = 13)		Age group 4 (50-59 years; n = 23)	
	BCTQ <2 (n = 5)	BCTQ ≥2 (n = 2)	BCTQ <2 (n = 5)	BCTQ ≥2 (n = 2)	BCTQ <2 (n = 9)	BCTQ ≥2 (n = 4)	BCTQ <2 (n = 14)	BCTQ ≥2 (n = 9)
PFr	14.10 (9.97–18.23)	15.50 (−16.27–47.27)	12.30 (9.18–15.42)	11.50 (−13.91–36.91)	15.22 (10.81–19.63)	15.25 (7.61–22.90)	14.86 (12.51–17.20)	13.89 (8.32–19.46)
PFl	15.30 (10.64–19.96)	16.50 (10.15–22.85)	14.30 (10.59–18.02)	12.25 (−35.40–59.90)	15.33 (12.07–18.60)	16.38 (8.00–24.75)	14.12 (12.19–16.03)	15.67 (10.00–21.34)
SUPr	31.40 (21.26–41.54)	36.75 (−125.25–198.75)	30.30 (26.56–34.04)	21.50 (2.44–40.56)	34.39 (24.91–43.87)	30.38 (16.85–43.90)	29.07 (25.69–32.45)	25.72 (21.37–30.08)
SUPl	30.10 (20.00–40.20)	41.00 (−98.77–180.77)	28.30 (24.08–32.52)	23.75 (−17.55–65.05)	32.94 (25.53–40.36)	27.25 (14.35–40.15)	27.18 (23.70–30.66)	25.89 (21.96–29.82)
PROr	25.30 (15.58–35.02)	26.75 (−97.14–150.64)	23.00 (20.12–25.88)	18.50 (12.15–24.85)	27.78 (21.09–34.47)	26.25 (14.04–38.46)	25.61 (22.20–29.02)	21.61 (17.00–26.22)
PROl	24.50 (16.85–32.15)	30.75 (−112.20–173.70)	23.40 (20.07–26.73)	19.00 (−50.88–88.88)	28.06 (22.93–33.19)	26.13 (12.60–39.65)	23.89 (20.49–27.29)	22.39 (18.31–26.46)
DEr	17.30 (10.55–24.05)	20.75 (4.87–36.63)	21.50 (13.31–29.69)	19.00 (19.00–19.00)	24.89 (16.75–33.03)	23.25 (15.66–30.84)	19.96 (15.39–24.54)	17.44 (10.95–23.94)
DEl	18.10 (11.75–24.45)	20.75 (−33.25–74.75)	20.40 (13.22–27.58)	18.25 (8.72–27.78)	23.06 (18.11–28.00)	21.38 (11.41–31.34)	19.57 (15.22–23.93)	16.17 (12.97–19.37)
NNr	30.70 (22.20–39.20)	34.75 (−70.08–139.58)	31.30 (29.51–33.09)	22.25 (19.07–25.43)	33.50 (26.19–40.81)	30.38 (20.67–40.08)	29.54 (26.97–32.10)	26.11 (20.95–31.28)
NNl	28.40 (20.11–36.69)	38.75 (−34.31–111.81)	28.10 (24.29–31.91)	35.50 (−14.62–61.62)	30.72 (25.31–36.14)	30.13 (18.57–41.68)	28.12 (24.92–31.29)	26.06 (22.31–29.80)

Note: Values shown are the mean (*M*) and 95 % confidence interval (CI 95 %) in kilogram, BCTQ=Boston Carpal tunnel Questionnaire, PFr = palmar flexion right, PFl = palmar flexion left, SUPr = supination right, SUPl = supination left, PROr = pronation right, PROl = pronation left, DEr = dorsal extension right, DEl = dorsal extension left, NNr = neutral right, NNl = neutral left.

HGS were found in participants with neck pain for pronation right ($F_{(1,49)} = 6.13$, $p = 0.02$, $\eta_p^2 = 0.11$), pronation left ($F_{(1,49)} = 4.07$, $p = 0.05$, $\eta_p^2 = 0.08$), and neutral right ($F_{(1,49)} = 5.70$, $p = 0.02$, $\eta_p^2 = 0.11$).

3.2. Effect of wrist pain on HGS in different age groups

Results for HGS in participants with and without wrist pain, separated by age groups and sex are shown in Tables 4 and 5. In male employees, significant differences were found in age group 4 for left hand palmar flexion ($F_{(1,24)} = 7.13$, $p = 0.01$, $\eta_p^2 = 0.24$), right hand supination ($F_{(1,24)} = 5.97$, $p = 0.02$, $\eta_p^2 = 0.21$), pronation right ($F_{(1,24)} = 6.02$, $p = 0.02$, $\eta_p^2 = 0.21$), dorsal extension right ($F_{(1,24)} = 8.07$, $p = 0.01$, $\eta_p^2 = 0.26$) and left ($F_{(1,24)} = 4.95$, $p = 0.04$, $\eta_p^2 = 0.18$), and neutral left ($F_{(1,24)} = 5.46$, $p = 0.03$, $\eta_p^2 = 0.19$) with lower HGS in the wrist pain group. If not separating age groups, significant differences were found for dorsal extension right with lower HGS in the wrist pain group ($F_{(1,94)} = 4.58$, $p = 0.04$, η_p^2=0.05).

For female employees, significant differences are found in age group 2 for right hand supination ($F_{(1,6)} = 13.56$, $p = 0.01$, $\eta_p^2 = 0.73$), right hand pronation ($F_{(1,6)} = 6.58$, $p = 0.05$, $\eta_p^2 = 0.57$), and right hand neutral ($F_{(1,6)} = 69.44$, $p < 0.001$, $\eta_p^2 = 0.93$), with lower HGS in the wrist pain group.

Across all by age groups and sex, significant differences between participants with and without wrist pain were found for supination right ($F_{(1,144)} = 6.05$, $p = 0.02$, $\eta_p^2 = 0.04$), supination left ($F_{(1,144)} = 4.10$, $p = 0.05$, $\eta_p^2 = 0.03$), pronation right ($F_{(1,144)} = 5.64$, $p = 0.02$, $\eta_p^2 = 0.04$), dorsal extension right ($F_{(1,144)} = 6.24$, $p = 0.01$, $\eta_p^2 = 0.04$), dorsal extension left ($F_{(1,144)} = 5.71$, $p = 0.02$, $\eta_p^2 = 0.04$), and neutral right ($F_{(1,144)} = 6.41$, $p = 0.01$, $\eta_p^2 = 0.04$), with lower HGS in participants with wrist pain.

3.3. Influence of age on HGS

Without consideration of neck or wrist pain, significant differences of HGS in male participants between the four age groups 18–29 (n = 15), 30-39 (n = 26), 40-49 (n = 29) and 50–59 (n = 25) were found for palmar flexion left ($F_{(3,94)} = 2.89$, $p = 0.04$, $\eta_p^2 = 0.09$) with significantly lower HGS in age group 4 than age group 3 (4.52, 95 % CI 0.36-8.68, $p = 0.03$). Furthermore, significant differences were found for supination right ($F_{(3,94)} = 4.16$, $p < 0.01$, $\eta_p^2 = 0.12$) with significantly lower HGS in age group 4 than age group 3 (7.92, 95 % CI: 1.44-14.39, $p < 0.01$), as well as for supination left ($F_{(3,94)} = 3.04$, $p = 0.03$, $\eta_p^2 = 0.09$) with significantly lower HGS in age group 4 than age group 3 (6.58, 95 % CI: 0.51-12.65, $p = 0.03$), and pronation right ($F_{(3,94)} = 3.11$, $p = 0.03$, $\eta_p^2 = 0.09$) with significant lower HGS in age group 4 than age group 3 (6.74, 95 % CI: 0.53-12.94, $p = 0.03$).

For female participants, no significant differences of HGS between the four age groups 18–29 (n = 7), 30–39 (n = 7), 40–49 (n = 13), and 50–59 (n = 23) were found.

Table 6
Correlations between the different outcome variables (Spearman-rho)

Variables	1	2	3	4	5
1. age					
2. weight	−0.003				
3. HGS neutral right	−0.25†	0.474†			
4. HGS neutral left	−0.225†	0.542†	0.898†		
5. NDI	0.142	−0.173*	−0.403†	−0.365†	
6. BCTQ	0.135	0.000	−0.229†	−0.153	0.515†

HGS = hand grip strength; NDI=Nordic Questionnaire; BCTQ=Boston Carpal Tunnel Questionnaire; *p < .05; †p < .01.

Table 7
Summary of hierarchical regression analysis for variables predicting HGS

Right hand	**Step 1**		**Step 2**		**Step 3**	
	B	ß	B	ß	B	ß
1. Age	−0.259	−0.249†	−0.209	−0.201†	−0.205	−0.197†
2. Weight	0.325	0.447†	0.289	0.398†	0.293	0.404†
3. NDI			−0.330	−0.327†	−0.301	−0.299†
4. BCTQ					−0.938	−0.057
R^2	0.252†		0.355†		0.357†	
Left hand						
1. Age	−0.207	−0.207†	−0.164	−0.164*	−0.164	−0.164*
2. Weight	0.373	0.534†	0.342	0.490†	0.341	0.489†
2. NDI			−0.284	−0.293†	−0.290	−0.298†
3. BCTQ					0.183	0.011
R^2	0.318†		0.400†		0.400†	

Legend: HGS = hand grip strength; NDI=Nordic Questionnaire; BCTQ=Boston Carpal Tunnel Questionnaire; Step 1: sex, age, weight; Step 2: NDI; Step 3: BCTQ; $^{*}p \le .05$; $^{\dagger}p < .01$.

3.4. Influence on HGS

Correlations between the outcome variables (age, weight, HGS right and left neutral, NDI, and BCTQ scores) are shown in Table 6. Significant correlations were found in HGS neutral and age, in HGS neutral and weight, HGS neutral left and neutral right, HGS neutral and NDI, NDI and weight, HGS neutral right and BCTQ, and BCTQ and NDI.

All steps of the regression analysis showed significance for the overall model (Table 7) with the highest R^2 for steps two and three. All steps revealed a significant influence of age, body weight, and NDI. Participants with lower HGS were older and had higher NDI scores. The analysis showed no effect of the BCTQ score on HGS.

4. Discussion and conclusion

The aim of this study was to analyze if the HGS in different wrist positions was affected by neck and/or wrist pain in male and female industrial employees with manual repetitive quality proofing tasks. Moreover, the influence of sex and age was evaluated. For this purpose, a large group of employees was examined with the goal to derive implications for future ergonomic practice.

Overall, neck pain can be considered as a main factor influencing HGS with reduced HGS for workers with neck pain. However, controlling for sex and age revealed that women are more affected by neck pain than men, especially the age group between 30−39 years.

The observed HGS was comparable to the reference HGS for these age groups reported by Bohannon et al. [18]. This can be explained by physiological adaptations to their working tasks in older workers including the adaptation of the HGS [7], which implies that the long-term manual work with a certain force results in force-related adaptions within the muscular system.

The comparison of the HGS in different wrist positions of participants with and without neck pain revealed that participants with neck pain showed reduced HGS in the neutral position. This suggests a strength reducing influence of neck pain on HGS. In this study, the reduction was observed in 68 % of the participants. The amount of neck pain is comparable to previous study results by Nordander et al. [50] and Nur et al. [51] and can therefore be assumed for other industrial sections. Interestingly, the influence of neck pain was also observed in the neutral wrist position, which should be the most ergonomic working posture due to the lowest pressure in the carpal tunnel [37,39].

Regarding the results for the participants with and without wrist pain, HGS was unsurprisingly reduced in participants with pain in nearly all wrist positions. As expected, the oldest age group of men showed the highest loss of HGS. In contrast, comparable to the results for neck pain, 30−39 years old women with wrist pain showed the lowest HGS.

The regression analysis confirmed these findings and identified sex, age, as well as NDI and wrist symptoms, as the factors significantly influencing the model.

The summary of our findings supports the hypothesis that neck disorders influence hand function which may be explained by the double crush phenomenon [44−46], even in participants with no obvious clinical indications for nerve root damage. These interactions were especially observed in young women. One might argue, that this combination of risk factors explains the three to four times higher prevalence of CTS in women [38]. This supports the importance of ergonomic solutions in industrial workplaces to reduce the risk for neck and wrist pain, especially for women.

For the left hand, we found the same results as for the right hand, but the results of the BTCQ did not predict the HGS. This might be explained by the workers' handedness and the predominant use of the right hand for their work tasks [62]. The observed age and sex effects are in line with previous findings, showing higher muscle strength in male than female participants and decreasing muscle strength with increasing age [18]. We, therefore, recommend the use of normative data for older women to estimate the maximum force limits of the work situation to create an equally ergonomic environment for both sexes.

The current data indicate that condition- and behavior-orientated interventions are required to reduce neck pain and the risk of wrist dysfunction at manual repetitive handling workstations. The overall ergonomic setting of workstations should be improved to address age-and sex-related reductions of HGS.

5. Limitations

One limitation of the study was that the HGS was not controlled for the handedness; thus, we were not able to distinguish between dominant and nondominant hand to compare subgroups and draw further conclusions concerning the distribution of HGS results. However, as shown in the results of the regression analysis, the results were comparable for both hands. Another limitation is the heterogeneous group sizes resulting in either unjustifiably significant or insignificant results which may have led to different interpretations and conclusions. Furthermore, it was not considered to compare HGS between sex. Especially, the smaller group of older women might have influenced the results. Future research should proof our study results with larger number of participants for the older age groups.

Funding sources

This study was funded by the German Trade Association Raw Materials and Chemical Industry with regard of the scientific concept.

Conflicts of interest

All authors have no conflicts of interest to declare.

Acknowledgments

The authors would like to acknowledge the support for this study provided by the automotive supplier Continental AG with numerous locations.

References

[1] Aboonq MS. Pathophysiology of carpal tunnel syndrome. Neurosciences 2015;20(1):4–9 (Riyadh).
[2] Potvin JR. Predicting maximum acceptable efforts for repetitive tasks: an equation based on duty cycle. Hum Factor. 2012;54(2):175–88.
[3] Didomenico A, Nussbaum MA. Measurement and prediction of single and multi-digit finger strength. Ergonomics 2003;46(15):1531–48.
[4] Greig M, Wells R. Measurement of prehensile grasp capabilities by a force and moment wrench: methodological development and assessment of manual workers. Ergonomics 2004;47(1):41–58.
[5] Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 1993;36(7):749–76.
[6] Carmeli E, Patish H, Coleman R. The aging hand. J Gerontol A Biol Sci Med Sci 2003;58(2):M146–52. https://doi.org/10.1093/gerona/58.2.M146.
[7] Chilima DM, Ismail SJ. Nutrition and handgrip strength of older adults in rural Malawi. Public Health Nutr 2001;4(1):11–7. https://doi.org/10.1079/PHN200050.
[8] Stenholm Sari, Tiainen Kristina, Rantanen Taina, Sainio Päivi, Heliövaara Markku, Impivaara Olli, Koskinen Seppo. Long-Term Determinants of Muscle Strength Decline: Prospective Evidence from the 22-Year Mini-Finland Follow-Up Survey. J Am Geriatr Soc 2012;60(1):77–85. https://doi.org/10.1111/j.1532-5415.2011.03779.x.
[9] Sternäng O, Reynolds CA, Finkel D, Ernsth-Bravell M, Pedersen NL, Dahl Aslan AK. Factors associated with grip strength decline in older adults. Age and Ageing 2015;44(2):269–74. https://doi.org/10.1093/ageing/afu170.
[10] Faisal CK, Mathew N, Mathias L, Ajith S. Grip strength and hand function changes in unilateral cervical radiculopathy. Int J Curr Res Rev 2012;4(21):82–90.
[11] Peolsson A, Ludvigsson ML, Wibault J, Dedering Å, Peterson G. Function in patients with cervical radiculopathy or chronic whiplash-associated disorders compared with healthy volunteers. J Manipulative Physiol Ther 2014;37(4):211–8. https://doi.org/10.1016/j.jmpt.2014.01.003.
[12] Savva C, Giakas G, Efstathiou M, Karagiannis C. Test-retest reliability of handgrip strength measurement using a hydraulic hand dynamometer in patients with cervical radiculopathy. J Manipulative Physiol Ther 2014;37(3):206–10. https://doi.org/10.1016/j.jmpt.2014.02.001.
[13] Mathur H, Singh A, Sharma A. Comparison of spinal mobilisation with arm movement (SMWAM) with conventional treatment on grip strength in patients with radiating neck pain. INROADS Int J Jaipur Natl Univ 2017;6(1):75–81.
[14] Lee JH, Yoo WG. Effects of head-neck rotation and kinesio taping of the flexor muscles on dominant-hand grip strength. J Phys Ther Sci 2010;22(3):285–9. https://doi.org/10.1589/jpts.22.285.
[15] Frederiksen H, Hjelmborg J, Mortensen J, McGue M, Vaupel JW, Christensen K. Age trajectories of grip strength: cross-sectional and longitudinal data among 8,342 Danes aged 46 to 102. Ann Epidemiol 2006;16(7):554–62. https://doi.org/10.1016/j.annepidem.2005.10.006.
[16] Mathiowetz V, Rennells C, Donahoe L. Effect of elbow position on grip and key pinch strength. J Hand Surg 1985;10(5):694–7. https://doi.org/10.1016/S0363-5023(85)80210-0.
[17] Puh U. Age-related and sex-related differences in hand and pinch grip strength in adults. Int J Rehabil Res 2010;33(1):4–11. https://doi.org/10.1097/MRR.0b013e328325a8ba.
[18] Bohannon RW, Peolsson A, Massy-Westropp N, Desrosiers J, Bear-Lehman J. Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. Physiotherapy 2006;92(1):11–5. https://doi.org/10.1016/j.physio.2005.05.003.
[19] Chaisson CE, Zhang Y, Sharma L, Kannel W, Felson DT. Grip strength and the risk of developing radiographic hand osteoarthritis: results from the Framingham Study. Arthritis Care Res 1999;42(1):33–8.
[20] Kjeken I, Dagfinrud H, Slatkowsky-Christensen B, Mowinckel P, Uhlig T, Kvien TK, Finset A. Activity limitations and participation restrictions in women with hand osteoarthritis: patients' descriptions and associations between dimensions of functioning. Ann Rheum Dis 2005;64(11):1633–8. https://doi.org/10.1136/ard.2004.034900.
[21] Russo A, Onder G, Cesari M, Zamboni V, Barillaro C, Capoluongo E, Pahor M, Bernabei R, Landi F. Lifetime occupation and physical function: a prospective cohort study on persons aged 80 years and older living in a community. Occup Environ Med 2006;63(7):438–42. https://doi.org/10.1136/oem.2005.023549.
[22] Gangopadhyay S, Ghosh T, Das T, Ghoshal G, Das BB. Prevalence of upper limb musculo skeletal disorders among brass metal workers in West Bengal, India. Ind Health 2007;45(2):365–70.
[23] Josty IC, Tyler MPH, Shewell PC, Roberts AHN. Grip and pinch strength variations in different types of workers. The J Hand Surg Br Eur 1997;22(2):266–9. https://doi.org/10.1016/S0266-7681(97)80079-4.
[24] Anakwe RE, Huntley JS, McEachan JE. Grip strength and forearm circumference in a healthy population. J Hand Surg Eur 2007;32(2):203–9. https://doi.org/10.1016/J.JHSB.2006.11.003.
[25] Werle S, Goldhahn J, Drerup S, Simmen BR, Sprott H, Herren DB. Age- and gender-specific normative data of grip and pinch strength in a healthy adult Swiss population. J Hand Surg Eur 2009;34(1):76–84. https://doi.org/10.1177/1753193408096763.
[26] Fess E, Moran C. Clinical assessment recommendations. American society of hand Therapists. Grip strength; 1981.
[27] El-Sais WM, Mohammad WS. Influence of different testing postures on hand grip strength. Eur Scient J ESJ 2014;10(36).
[28] Murugan S, Patel D, Prajapati K, Ghoghari M, Patel P. Grip strength changes in relation to different body postures, elbow and forearm positions. Int J Physiother Res 2013;1(4):116–21.
[29] Richards LG, Olson B, Palmiter-Thomas P. How forearm position affects grip strength. Am J Occup Ther 1996;50(2):133–8. https://doi.org/10.5014/ajot.50.2.133.
[30] Bhardwaj P, Nayak SS, Kiswar AM, Sabapathy SR. Effect of static wrist position on grip strength. Indian J Plast Surg 2011;44(1):55–8. https://doi.org/10.4103/0970-0358.81440.
[31] Bhuanantanondh P, Nanta P, Mekhora K. Determining sincerity of effort based on grip strength test in three wrist positions. Saf Health Work 2017. https://doi.org/10.1016/j.shaw.2017.06.001.
[32] Baker NA, Moehling KK, Desai AR, Gustafson NP. Effect of carpal tunnel syndrome on grip and pinch strength compared with sex- and age-matched normative data. Arthritis Care Res 2013;65(12):2041–5. https://doi.org/10.1002/acr.22089.
[33] Mora AN, Blazar PE. Upper extremity nerve entrapment. In: Katz JN, Blauwet CA, Schoenfeld AJ, editors. Principles of orthopedic practice for primary care providers. [S.l.]. Springer; 2018. p. 253–66.
[34] Gelberman RH, Hergenroeder PT, Hargens AR, Lundborg GN, Akeson WH. The carpal tunnel syndrome. A study of carpal canal pressures. JBJS 1981;63(3):380–3.
[35] Loh PY, Muraki S. Effect of wrist angle on median nerve appearance at the proximal carpal tunnel. PLoS ONE 2015;10(2):e0117930. https://doi.org/10.1371/journal.pone.0117930.
[36] Schmidt HM. Chirurgische Anatomie des Karpaltunnels. Handchir Mikrochir Plast Chir 2006;38(5):283–95. https://doi.org/10.1055/s-2006-923848.
[37] You D, Smith AH, Rempel D. Meta-analysis: association between wrist posture and carpal tunnel syndrome among workers. Saf Health Work 2014;5(1):27–31. https://doi.org/10.1016/j.shaw.2014.01.003.
[38] Assmus H, Antoniadis G, Bischoff C. Carpal and cubital tunnel and other, rarer nerve compression syndromes. Deutsches Ärzteblatt Int 2015;112(1–2):14–25. https://doi.org/10.3238/arztebl.2015.0014.
[39] Amin DI, Hawari MZ, Hassan HES, Elhafez HM. Effect of sex and neck positions on hand grip strength in healthy normal adults: a cross-sectional, observational study. Bull Fac Phys Ther 2016;21(1):42. https://doi.org/10.4103/1110-6611.188028.
[40] Hansraj KK. Assessment of stresses in the cervical spine caused by posture and position of the head. Surg Technol Int 2014;25:277–9.
[41] Upton AR, McComas AJ. The double crush in nerve entrapment syndromes. Lancet 1973;2(7825):359–62.
[42] Cohen BH, Gaspar MP, Daniels AH, Akelman E, Kane PM. Multifocal neuropathy: expanding the scope of double crush syndrome. J Hand Surg Am 2016;41(12):1171–5. https://doi.org/10.1016/j.jhsa.2016.09.009.
[43] Molinari WJ, Elfar JC. The double crush syndrome. J Hand Surg 2013;38(4):799–801. https://doi.org/10.1016/j.jhsa.2012.12.038.
[44] Moberg LL, Lunde L-K, Koch M, Tveter AT, Veiersted KB. Association between VO2max, handgrip strength, and musculoskeletal pain among construction and health care workers. BMC Public Health 2017;17(1):272. https://doi.org/10.1186/s12889-017-4173-3.
[45] Fayez ES. The correlation between neck pain and hand grip strength of dentists. Occup Med Health Aff 2014;2(5):1–4. https://doi.org/10.4172/2329-6879.1000185.
[46] Kohli JK, Thurkral H. A study on relationship between neck pain and handgrip strength in dentists as an occupational hazard. Al Ameen J Med 2018;11(1):27–30.
[47] Novak CB. Upper extremity work-related musculoskeletal disorders: a treatment perspective. J Orthop Sports Phys Ther 2004;34(10):628–37. https://doi.org/10.2519/jospt.2004.34.10.628.
[48] Bepko J, Mansalis K. Common occupational disorders: asthma, COPD, dermatitis, and musculoskeletal disorders. Am Fam Physician 2016;93(12):1000–6.
[49] Nordander C, Hansson G-Å, Ohlsson K, Arvidsson I, Balogh I, Strömberg U, Rittner R, Skerfving S. Exposure–response relationships for work-related neck and shoulder musculoskeletal disorders – Analyses of pooled uniform data sets. Appl Ergon 2016;55:70–84. https://doi.org/10.1016/j.apergo.2016.01.010.
[50] Nordander C, Ohlsson K, Åkesson I, Arvidsson I, Balogh I, Hansson G-Å, Strömberg U, Rittner R, Skerfving S. Exposure–response relationships in work-related musculoskeletal disorders in elbows and hands–A synthesis of

group-level data on exposure and response obtained using uniform methods of data collection. Appl Ergon 2013;44(2):241–53.
[51] Nur NM, Dawal SZM, Dahari M, editors. The prevalence of work related musculoskeletal disorders among workers performing industrial repetitive tasks in the automotive manufacturing companies 2014.
[52] Mozafari A, Vahedian M, Mohebi S, Najafi M. Work-related musculoskeletal disorders in truck drivers and official workers. Acta Med Iranica 2015;53(7): 432–8.
[53] Cramer H, Lauche R, Langhorst J, Dobos GJ, Michalsen A. Validation of the German version of the neck disability index (NDI). BMC Musculoskelet Disord 2014;15(1):91. https://doi.org/10.1186/1471-2474-15-91.
[54] Swanenburg J, Humphreys K, Langenfeld A, Brunner F, Wirth B. Validity and reliability of a German version of the neck disability index (NDI-G). Man Ther 2014;19(1):52–8. https://doi.org/10.1016/j.math.2013.07.004.
[55] Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. J Manipul Physiol Ther 1991;14(7):409–15.
[56] de Carvalho Leite J, Jerosch-Herold C, Song F. A systematic review of the psychometric properties of the Boston Carpal Tunnel Questionnaire. BMC Musculoskelet Disord 2006;7:78. https://doi.org/10.1186/1471-2474-7-78.
[57] Keilani MY, Pernicka E, Paternostro-Sluga T, Sycha T, Schett G, Pieber K, Fialka-Moser V, Crevenna R. Übersetzung und Validierung des “Boston Carpal Tunnel Syndrome Questionnaire” zum Einsatz bei deutschsprachigen Patienten. Phys Med Rehab Kuror 2008;18(03):136–44.
[58] Amadio PC, Silverstein MD, Ilstrup DM, Schleck CD, Jensen LM. Outcome assessment for carpal tunnel surgery: the relative responsiveness of generic, arthritis-specific, disease-specific, and physical examination measures. J Hand Surg Am 1996;21(3):338–46.
[59] Levine DW, Simmons BP, Koris MJ, Daltroy LH, Hohl GG, Fossel AH, Katz JN. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. J Bone Joint Surg (Am Vol) 1993;75(11):1585–92.
[60] Heybeli N, Kutluhan S, Demirci S, Kerman M, Mumcu EF. Assessment of outcome of carpal tunnel syndrome: a comparison of electrophysiological findings and a self-administered Boston questionnaire. J Hand Surg 2002;27(3):259–64. https://doi.org/10.1054/jhsb.2002.0762.
[61] Reis MM, Arantes PMM. Medida da força de preensão manual- validade e confiabilidade do dinamômetro saehan. Fisioter Pesqui 2011;18(2):176–81. https://doi.org/10.1590/S1809-29502011000200013.
[62] McManus IC. The history and geography of human handedness. Lang Lateralization Psychosis 2009:37–57.