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Original Article

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

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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.

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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

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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 precision 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)
PfI	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 (41.56–57.3)	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)
SUPI	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)
PROI	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)
DEI	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)
NNI	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, PFI = palmar flexion left, SUPr = supination right, SUPr = supination left, PROr = pronation right, PROI = pronation left, DEr = dorsal extension right, DEI = dorsal extension left, NNr = neutral right, NNI = 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 = 2)	BCTQ ≥2 (n = 5)	BCTQ <2 (n = 2)	BCTQ ≥2 (n = 5)	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)	11.50 (–13.91–36.91)	12.30 (9.18–15.42)	15.22 (10.81–19.63)	15.25 (7.61–22.90)	14.86 (12.51–17.20)	13.89 (8.32–19.46)
PFI	15.30 (10.64–19.96)	16.50 (10.15–22.85)	12.25 (–35.40–59.90)	14.30 (10.59–18.02)	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)	21.50 (2.44–40.56)	30.30 (26.56–34.04)	34.39 (24.91–43.87)	30.38 (16.85–43.90)	29.07 (25.69–32.45)	25.72 (21.37–30.08)
SUPI	30.10 (20.00–40.20)	41.00 (–98.77–180.77)	23.75 (–17.55–65.05)	28.30 (24.08–32.52)	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)	18.50 (12.15–24.85)	23.00 (20.12–25.88)	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)	23.40 (20.07–26.73)	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)	19.00 (19.00–19.00)	21.50 (13.31–29.69)	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)	18.25 (8.72–27.78)	20.40 (13.22–27.58)	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)	31.30 (29.51–33.09)	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)	28.10 (24.29–31.91)	35.50 (–14.62–61.62)	30.72 (25.31–36.14)	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, PFI = 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 ($F_{(1,94)} = 4.58, p = 0.04, \eta_p^2 = 0.05$).

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	β	B	β	B	β
	1. Age	-0.259	-0.249 [†]	-0.209	-0.201 [†]	-0.205
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						
	Step 1		Step 2		Step 3	
	B	β	B	β	B	β
	1. Age	-0.207	-0.207 [†]	-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; * $p \leq .05$; [†] $p < .01$.

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 R² 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 adaptations 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 BCTQ 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-oriented 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.

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Conflicts of interest

All authors have no conflicts of interest to declare.

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