Evaluation of Effect of Handle Vibration Diesel-Fueled Single-Axle Tractor on Handgrip Strength of Operators

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Research Article

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Abstract

Background: The transmission of vibration from a single-axis tractor to the human body is determined by its dynamic response; this, in turn, depends on the physical characteristics of a person's hand, the contact area, the strength of the grip, the push force of the tractor, and the position. The purpose of this work was to measure and evaluate handgrip strength and fatigue resistance for operators of a 15 horsepower single-axle tractor before and after vibration exposure.

Methods: Grip strength of dominant and non-dominant hands before and after 30 minutes of tilling operations was measured and recorded. The operators performed tilling tasks with the tractor in third gear, while the vibration levels were measured at the tractor handle along with the vertical, forward, and transverse directions.

Results: The average operator grip strength was 33.6 ± 2.7 and 26.3 ± 3.3 kg and the average overall grip strength declined from 39.7 to 29.31 kg, although the average fatigue strength was 27.6 and 26.5 seconds for the dominant hand before and after vibration exposure. For the non-dominant hand, the mean grip strength measured was 28.7±2.9 and 23.1±1.9 kg and the maximum grip strength was 32.79 and 26.25, while fatigue was 29.76 and 22 seconds before and after tilling respectively.

Conclusion: The average reduction in grip strength suggest considerable differences in grip strength for dominant and non-dominant hands of single axle tractor operators and shows that vibration transmitted from the single axle tractor handle has a major effect on the operators.

Background

During several hours of farming, operators of single-axle tractors are subjected to large quantities of hand vibration. Vibration feedback from most power tools to the hand contains inputs from all three orthogonal motion axes and frequency-weighted RMS acceleration values for vertical, forward and lateral direction measured as a_{hwx}, a_{hwy}, and a_{hwz} are recorded separately using the frequency-weighting graph, respectively[1].

Hand-tractor coupling forces are the main quantities for calculating hand-transmitted vibration; they must be continuously measured during physiological effects studies [2, 3]. According to the Griffin study[4], the vibration transmission is largely determined by the dynamic response of the hand; this, in turn, depends on the physical characteristics of the individual hand, the contact area, the grip force, the push force, the location, etc. The effect of these variables can be quantified by calculating the energy used by the hand instead of the vibration frequency on the tool handle. Friction forces tangential to the surface of the handle are linked to the grip strength originating from the grip contact pressure normal to the handle surface[5, 6].

Long-term vibration damage from vibratory equipment results in muscle fatigue affecting grip strength[7] and research performed on different occupational groups, such as cleaners, dental hygienists, dental

technicians, dentists, drivers, metalworkers, and wood product assemblies, suggested that the most common symptoms were numbness and loss of grip strength [8].

Grip strength can be used as a quantitative measure of the efficiency of the sensor motor capacity of the user; it also serves as an indication of the applicability of the device to the task. Schlüssel et al. [9] described the grip strength as an integral part of the contact pressure over the entire hand and the contact surface; it was noted that the subject received increasing attention from industrial engineers and ergonomics researchers.

Research has shown that on average individual maximal handgrip strength is associated with anthropometric indicators such as gender, age, body weight, dominant hand, hand length, and hand width [10, 11] and the transfer of vibration energy to the hand is primarily influenced by the contact forces between the hands and the gripping zones.

In addition to the direct increase in hand vibration level with grip strength; the muscle tension causes phase shifts in the vibration[12–14]. Hewitt [15] has shown that vibratory tool operators such as impact hammers, grinders, and pneumatic hammers exert high grip strengths that enhance the transfer to operators of vibration energy. Research has shown that grip strength generally depends on age, with younger operators having relatively high grip strength; grip strength then decreases with age for both the dominant and non-dominant hands[16, 17]. Another study [18] found that in the dominant hand, grip strength is typically higher. According to Dong et al.,[19] grip strength measurements generally depend on the orientation of the measurement axis and that the maximum value can be significantly different from the minimum value in a given gripping action. Several studies have been conducted to find age-dependent reference (baseline) grip strength[20–23].

Workers who apply frequent forceful gripping and moving forces to vibratory tool handles may be at risk of developing circulatory, neurological, or musculoskeletal disorders. These disorders have been grouped as hand-arm vibration syndrome (HAVS). HAVS covers neurological, vascular and musculoskeletal injuries[24].

Several studies have shown that grip strength predicts upper extremity weakness and improves muscle strength, physical movement and range of motion, hand dexterity, and ability to perform day-to-day operations [25–27].

The strength decrement index (SDI) was defined by Endurance [28], which is the fractional decrease in Grip Strength due to fatigue calculated by the formula:

$$SDI = \frac{IS - FS}{IS} * 100 \qquad (3)$$

Where IS = initial Grip Strength

FS = final Grip Strength

Of special concern is muscle fatigue arising from repeated hand surgery. With a sufficiently vigorous and extended duration of exercise, the mechanical strength of the skeletal muscles decreases. Fatigue can be defined as a progressive decline in muscle performance during exercise, or an exercise-induced reduction in the ability to exert muscle force or power[29]. In cases where the operator uses maximum force, or experiences high-frequency fatigue, the maximum grip strength available generally shows a rapid decline during work; however, there is generally a rapid recovery from this type of fatigue[29].

Several researchers [30,31]described fatigue resistance for each hand as the time for grip strength to decrease to 50% of its maximum value. Bautmans et al [32] described "grip work" (GW) as an integral part of GS grip strength over fatigue resistance time (FR), where FR is the time for grip strength to decrease to half of its maximum value. (**figure 1**).

GW » 0.75 * GS * FR (4)

Where GW = grip work,

GS = maximum grip strength

FR = fatigue resistance

This paper presents data on measurements of grip strength, fatigue resistance, grip work and strength decrement index for operators of a 15 horsepower single-axle tractor operator, before and after 30 minutes of ground tilling activities.

Methods

Experimental layout

At the Melkasa Agricultural Research Center (MARC), located 117 km east of Addis Ababa, an evaluation of the vibration characteristics of hand-arm transmitted vibration originating from a single-axle tractor was carried out. The region is characterized by arid to semi-arid agro-ecological zones at an altitude of 1550 meters above sea level with temperatures normally between 14 °C and 28 °C, mean annual precipitation between 750 and 800 mm, length of the growth period (LGP) between 3 and 6 months, and volcanic sandy soils with a pH between 7 and 8.2.

Equipment

Equipment used for handgrip strength measurement of tractor operators included an SS25LA Hand Dynamometer, Biopac MP35 data acquisition system, and Biopac student Lab Lessons and PRO version 3.7.1 software for Win98SE, Me,2000, XP. The system is shown in Figure 2.

The MP 35 data acquisition unit (Biopac Systems Inc, USA) has four channels with sampling rates ranging from 1 to 100k samples per second and 24-bit resolution. The MP35 has an internal microprocessor to control data acquisition from the dynamometer and communication with the computer. The calibration sequence recommended by the manufacturer was used for the dynamometer before conducting the experiments.

Subjects and tasks

Seven (7) male subjects participated in the operation of the 15-HP single-axle tractor. Grip strength of dominant and non-dominant hands before and after 30 minutes of tilling operations was measured and recorded. The operators performed tilling tasks with the tractor in third gear, while the vibration levels were measured at the tractor handle along the vertical, forward, and transverse directions.

The test method for measuring grip strength started with the dominant forearm, with a phased increase in clenches in increments of 5kg until the full grip strength was reached. Fatigue resistance specified as the time for maximum grip strength to decrease to 50 per cent of its initial value has also been calculated. This process was then replicated for the non-dominant forearm of all operators.

Results

Handle vibration

During single-axle tractor operations, the mean single-axle vibration tractor was determined in vertical, forward and lateral directions for seven (7) operators. In the longitudinal, forward and lateral directions, the mean observed single-axle tractor handling vibration was 22.61 ± 2.92, 11.33 ± 1.81 and 20.79 ± 2.47 m/s^2 respectively. The result reveals that the highest vibration values of the single axle tractor were in the vertical direction, while the lowest were in the forward direction. The mean measured overall vibration value (ahv) and daily vibration exposure A (8) of the single axle tractor were 32.74 and 12.10 m/s^2 respectively.

Grip strength

The grip power of the dominant and non-dominant hands of seven single-axle tractor operators was measured using the dynamometer before and during single-axle tractor operation. The mean grip strength for the dominant hand was 33.6±2.7 and 26.3±3.3 kg of force, while for the non-dominant hands, the measurements were 28.67 ± 2.9 and 23.14 ± 1.9 kg of force before and after single-axle tractor operation.

The mean measured maximum and minimum grip strength for a dominant hand before vibration exposure or tractor operation was 39.70 and 27.35 kg force, and after operation the maximum and minimum grip strength was 27.35 and 18.46 kg force respectively. The mean measured maximum and

minimum grip strength for a non-dominant hand before vibration exposure or tractor operation was 32.79 and 26.25 kg force, and after operation the maximum and minimum grip strength was 32.25 and 20.75 kg force respectively.

Grip strength fatigue resistance

For the dominant hand, average fatigue resistance for all seven tractor operators varied between 27.6 and 26.5 seconds before and after respectively (**figure 3**). The corresponding fatigue resistance for the non-dominant hand was 29.76 and 22 seconds before and after vibration exposure respectively.

Endurance is an important physical fitness factor that needs to be taken into consideration when analyzing musculoskeletal functions. Measurements were made by 7 test subjects on mean grip strength scores before and after 30 minutes of single-axle tractor operation. The average estimated strength decrement index (SDI) was calculated according to Equation (3) from the operators' assessed grip strength before and after the single-axle tractor action and was found to be 28.6 per cent.

Grip Work

The grip work was calculated in compliance with equation (4) and was found to be 709 ± 213 and 523 ± 208 kg-s for the dominant hand in the seven test subjects before and after 30 minutes of single-axle tractor operation. Statistically, before and after the process, there is no substantial difference between the means of grip function ($p = 0.15$, that is, $p > 0.05$). However, during the tractor operation, there was a statistical mean decline in both grip power and fatigue resistance ($p < 0.005$).

Discussions

The mean grip strength of single-axle tractor operators showed a decrease of 7.3 kg (21.7 per cent) in the dominant handgrip strength after vibration sensitivity with a cumulative vibration value of 32.74 m/s^2 and consistent with the results of M Widia & Dawal [33] who carried out 5-minute grip tests on an electrical drill with a mean vibration level of 10.45 m/s^2 resulting in a reduction of 24.5 per cent in grip strength. Subsequently, further 15-minute trials with 10.7 m/s^2 vibration levels were conducted and a drop in grip strength of 29.2 per cent was found, a significantly higher decrease than was seen in the 5-minute measurements. Before and after 1 hour of rock drilling by stone crushers, Rashid et al. [34] reported an average decrease in grip strength of 5.86 kg (10.8 per cent).

The average measurement of handgrip strength of single axle tractors operators was compared with baseline with different findings: the dominant hand mean grip strength of single axle tractor operator before was 33.6 ± 2.7 kg ($p = 0.065$, i.e. $p > 0.05$) at baseline with an absolute change of -7.4 kg and after vibration exposure the mean 26.3 ± 3.3 kg ($p = 0.007$, i.e. $p<0.05$) at baseline with an absolute change of -14.7 kg. The non-dominant hand mean grip strength of single axle tractor operator before was 28.7 ± 2.9

kg (p=0.014, i.e. p < 0.05) at baseline with absolute change of -12.32 kg and after vibration exposure the mean 23.3 ± 1.9 kg (p = 0.004, i.e. p < 0.05) at baseline with absolute change of -17.72 kg.

In several studies[7, 35, 36], decreased grip strength with vibration sensitivity has also been reported, and exposure to hand-arm vibration over time results in reduced hand output [7, 13, 35, 37].

The mean measured grip strength was assessed for seven (7) operators before and after single-axle tractor operation using Two-way ANOVA and the impact of single-axle tractor grip vibration was observed. P-values of the handgrip force of single-axle tractor operators for vibration exposure before and after single-axle tractor operation (the p-value < 0.0001, for α = 0.05) are provided in the ANOVA table (4) in column Prob>F.

The p-value indicates that the means of the handgrip strength of single axle tractor operators before and after single axle tractor handle vibration exposure are significantly different. The box plots are used to show overall patterns of operators' handgrip strength change in responses to the handle vibration of a single axle tractor. They provide a useful way to visualize the range and other characteristics of responses for a large group. As shown in figure (4) all the four (4) medians for both dominant and non-dominant handgrip strength before and after single axle tractor handle vibration exposure are significantly different at the 5% significance level and their intervals do not overlap.

Vibration exposure-related handgrip strength dysfunction is a major risk factor associated with hand-arm vibration syndrome (HAVS). For all forms of vibrating devices, deterioration of handgrip power impairment may be caused by hand transmitted vibration sensitivity behaviours [38].

The results of handgrip fatigue resistance found in this research are consistent with those of Alkurdi and Dweiri,[30] who examined the relationship between handgrip strength and fatigue for various anatomical configurations of operator work. They found fatigue resistance varied between 26.2 and 35.4 seconds for the right hand and from 23.2 to 40 seconds for the left hand.

The estimated strength decrement index (SDI) is consistent with the 23 per cent SDI value calculated for a power grip analyzer operator [28]. White et al.,[39] observed a mean value of the power decrement index of 29.8 per cent in a separate test.

Deterioration of handgrip capacity is an indication of the development of musculoskeletal diseases of the upper extremity [40]. Several studies [41–43] have shown that workers subjected to vibratory hand tools suffer from pain, muscle weakness, resulting in musculoskeletal disorders due to diminished grip ability, fatigue, and reduced performance.

A substantial decrease in the overall grip strength measured after 30 minutes of tilling operation was caused by vibration of the single-axle tractor. Statistical analysis showed that in both the dominant and non-dominant hands, there was a substantial difference in the mean value of the grip strength before and after tilling operations (P<0.05). In general, the effect the single axle handle vibration has an impact on the operators' handgrip strength and made large variance between the measured mean grip strength.

Limitations

This study is limited to the measurement of handgrip strength of single axle tractor operators before and after operation of single axle tractor and analyzing the effect of handle vibration on handgrip strength of operators while measuring the handle vibration during the operation of single axle tractor.

Conclusions

For the dominant hand, the average fatigue resistance (the time to reach 50% fatigue of maximum grip strength) before and after vibration exposure for 30 minutes was 27.6 and 26.5 seconds, respectively. The averaged mean operator grip strengths were 33.6 ± 2.7 and 26.3 ± 3.3 kg force difference of 7.3 kg (21.7 %) and the average maximum decreased from 39.7 to 29.31 kg of grip strength with the difference of 10.39 kg (25.97%) for a dominant hand before and after 30 minutes of vibration exposure respectively; this was determined to be statistically significant ($P<0.05$). Corresponding values for the non-dominant hand were 28.7 and 23.1 kg force difference of 5.6

The equivalent non-dominant hand values were 28.7 and 23.1 kg force difference of 5.6 kg (19.5 per cent) and the mean maximal grip strength declined from 32.79 to 26.25 kg, respectively, with a difference of 6.54 kg (19.95 per cent) before and after exposure to vibration. The findings indicate a substantial average grip force difference of 7.3 and 5.6 kg, respectively, between the dominant and non-dominant hands of single axle tractor operators, and confirm that the vibration transmitted from the single axle tractor handle was greatly influenced by the operators.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Ethical review committee of Addis Ababa University, Ethiopia with the reference number of 1844/02/2020. The study didn't involve invasive procedures and was conformed to the Declaration of Helsinki. Following a detailed explanation about the objectives and indirect benefits of the study, written and informed consent was obtained from each study participant. Confidentiality of the respondents was kept.

Consent for publication

Not Applicable.

Availability of data and materials

The datasets used and/or analyzed during the present study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' Contributions

The authors contributed to the work; the fieldwork carried out by SB under the leadership of DW for the evaluation of control power and health-related concerns for the measurement of single-axle tractor operator vibration and handgrip strength, and the manuscript draft was also carried out by SB; AS, DW and DR. All the authors' read and accepted the final manuscript.

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Tables

Table 1 ANOVA table of grip strength before and after vibration exposure

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	406.234	3	135.411	12.63	3.72262e-05
Rows	0	0	NaN	NaN	NaN
Interaction	0	0	Inf	Inf	NaN
Error	257.216	24	10.717		
Total	663.45	27			

tbl = 6×6 cell array

{'Source'}	{'SS'}	{'df'}	{'MS'}	{'F'}	{'Prob>F'}
{'Columns'}	{[406.2339]}	{[3]}	{[135.4113]}	{[12.6348]}	{[3.7226e-05]}
{'Rows'}	{[0]}	{[0]}	{[NaN]}	{[NaN]}	{[NaN]}
{'Interaction'}	{[1.7621e-12]}	{[0]}	{[Inf]}	{[Inf]}	{[NaN]}
{'Error'}	{[257.2164]}	{[24]}	{[10.7173]}	{0×0 double}	{0×0 double}
{'Total'}	{[663.4502]}	{[27]}	{0×0 double}	{0×0 double}	{0×0 double}

Figures

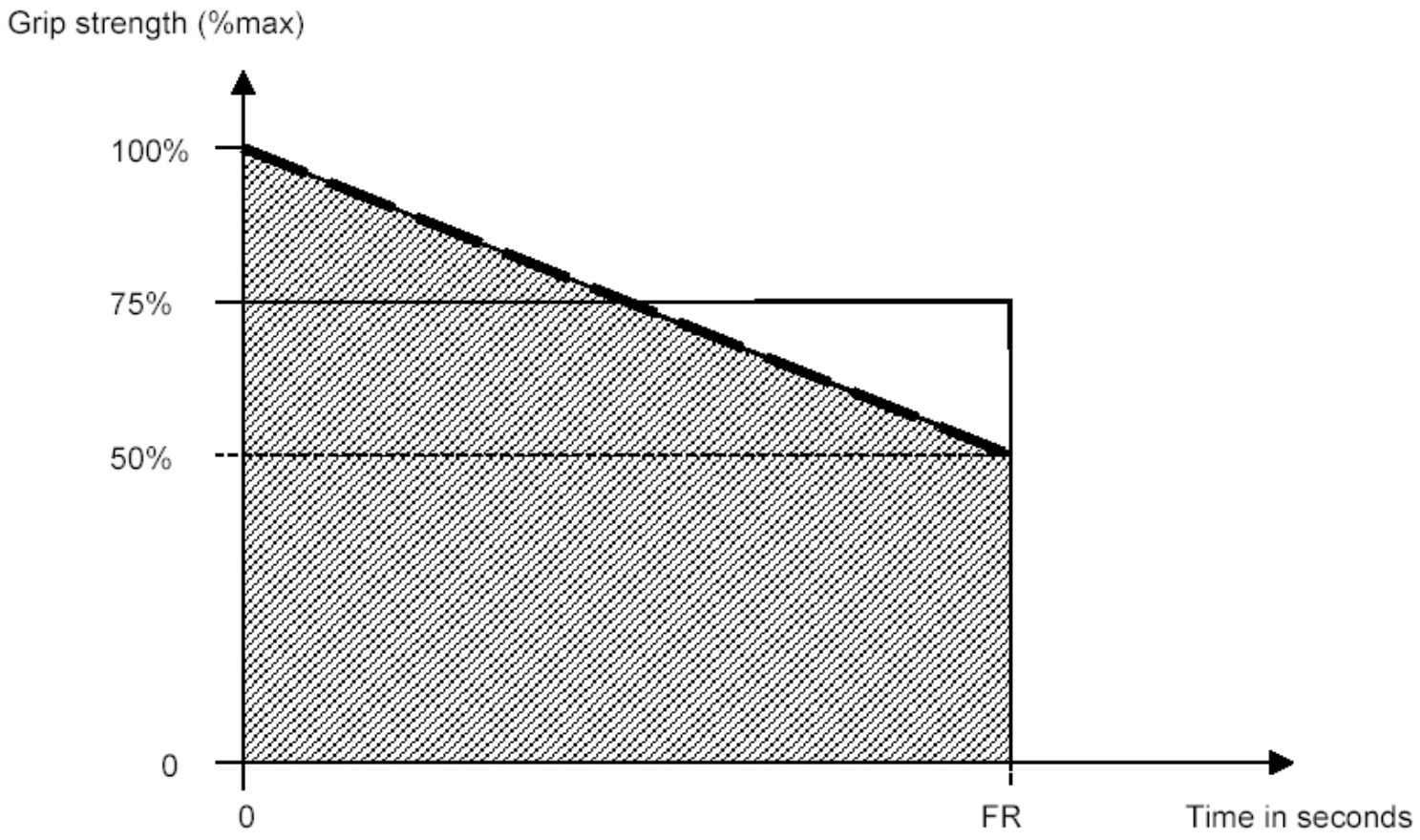

Figure 1

Schematic representation of grip work [32]

Four Channel Data acquisition Unit MP 35
(Biopac Systems Inc, USA)

Figure 2

Real-time standard data acquisition unit MP 35 (Biopac Systems Inc, USA) with SS25LA hand dynamometer

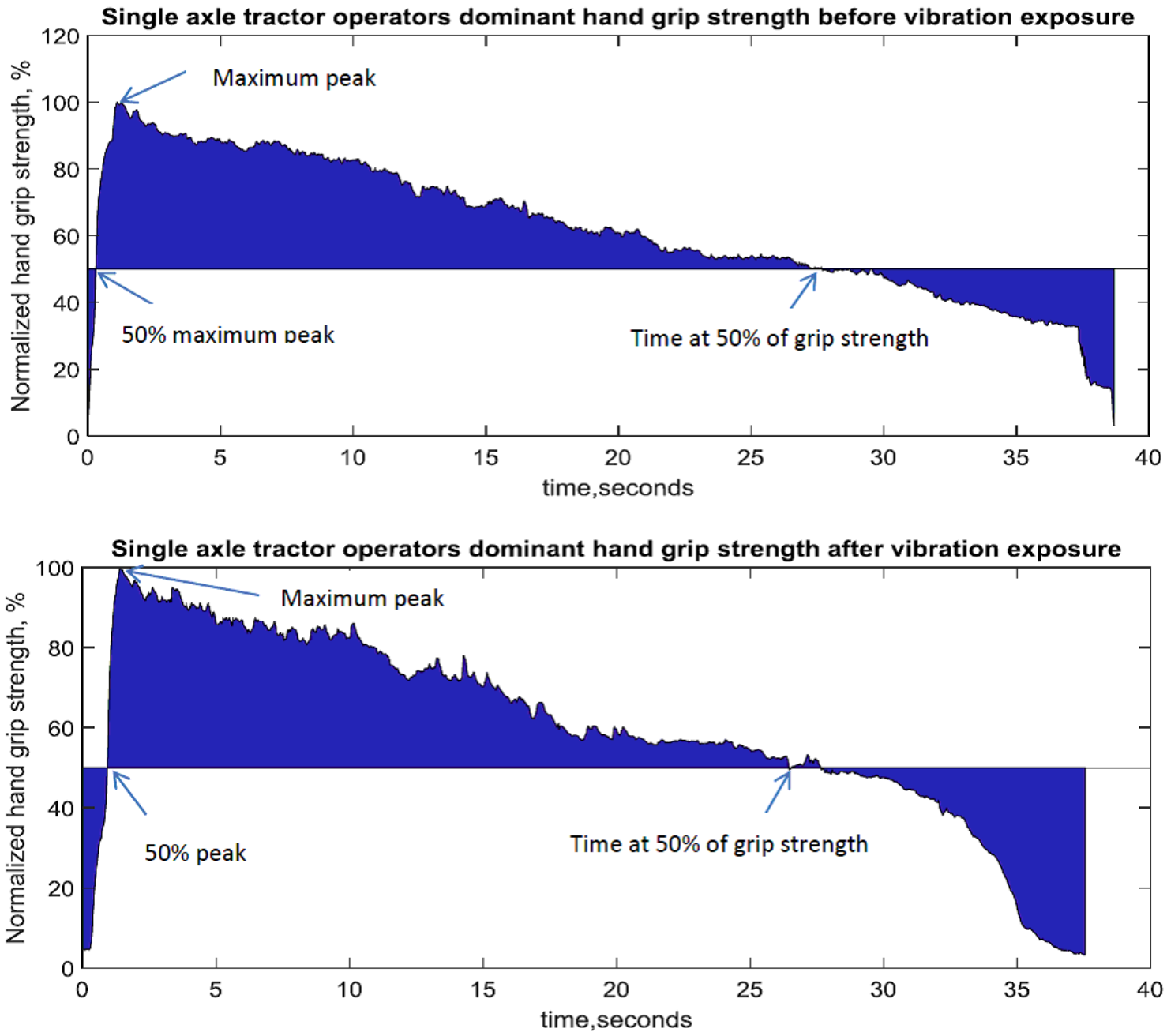

Figure 3

Average maximum grip strengths for the right (dominant) hand before and after operation of the single-axle tractor for 30 minutes

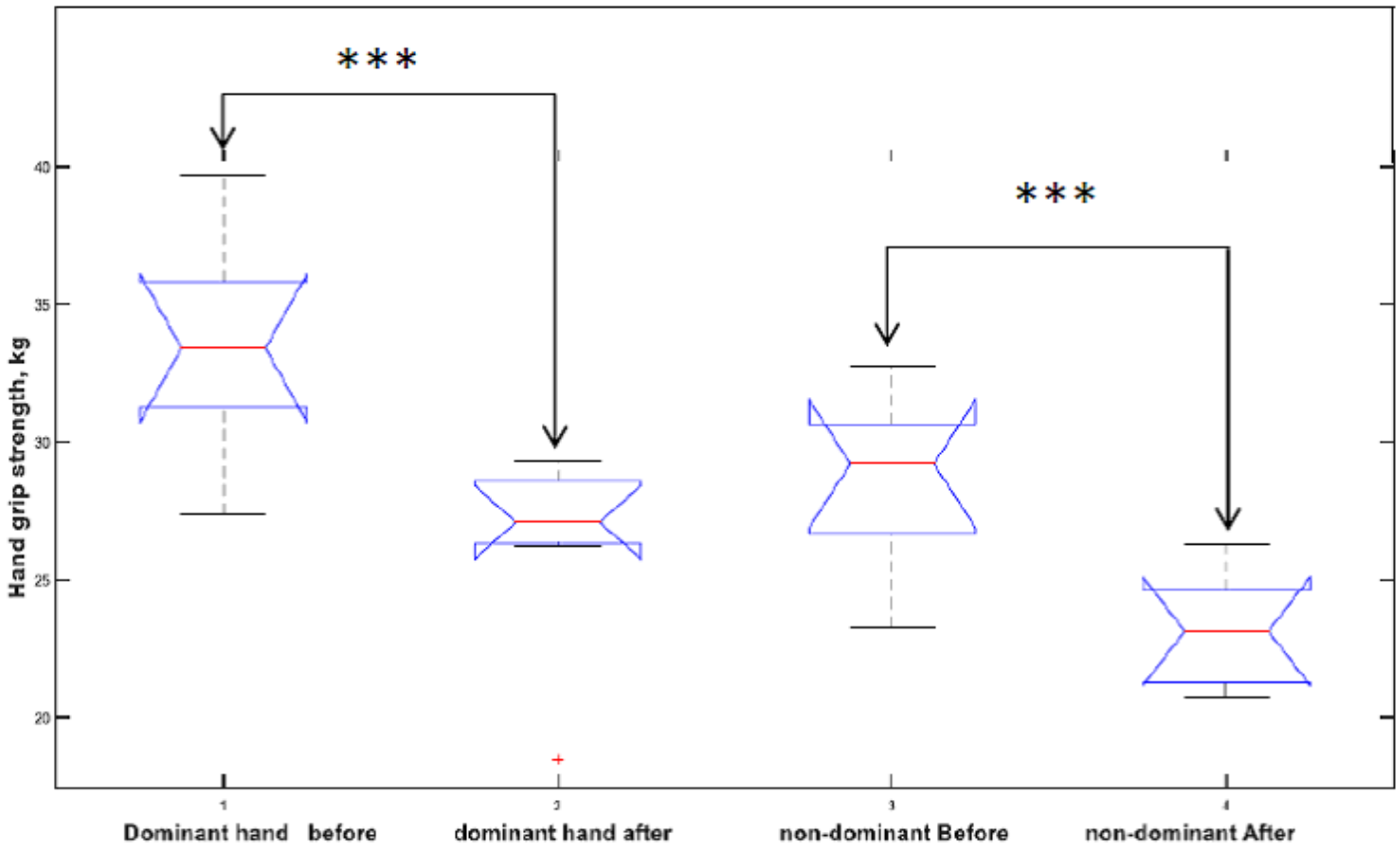

Figure 4

Boxplot of dominant and non-dominant hand before after vibration exposure *** Significant difference, ($p < 0.0001$, for $\alpha = 0.05$)