Applied Ergonomics 50 (2015) 133–138

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Adapting the force characteristics of a staple gun to the human hand

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ARTICLE INFO

Article history:
Received 28 March 2014
Accepted 5 March 2015
Available online 31 March 2015

Keywords:
Hand
Repetitive work
Tool

ABSTRACT

Three prototype staple guns with modified force characteristics were compared with a commercially available standard staple gun with a linearly increasing force resistance during squeezing. The force characteristics of the prototypes were more or less adapted to the force characteristics of the human hand, and in one of the staple guns the general force level was also reduced by one third. Evaluation instruments were electromyography of the forearm flexors and extensors, subjective rating of forearm exertion and subjects' free comments about the four tools. Twelve professional craftsmen were recruited as test subjects. The results show significantly lower readings for two of the three prototypes compared with the standard gun in electromyography as well as subjective ratings. The squeezing times are also reduced for two of the prototypes. It is concluded that the choice of force characteristics of a staple gun is important both to minimize forearm muscular exertion and to increase tool efficiency.

1. Introduction

A staple gun (SG) is a common tool for both professional and domestic use. Different sizes of guns are available on the market, some manually operated (see example in Fig. 1) and some externally powered. The former type is the predominant tool for domestic use, but is also commonly employed by professional craftspeople, as it does not need a battery or external power connection.

Repetitive hand work, as performed with an SG, is considered to be a risk factor for work-related musculoskeletal disorders (Luopajärvi et al., 1979; Armstrong et al., 1986; Dimberg, 1987; Silverstein et al., 1987; Kroemer, 1989). Common disorders reported are carpal tunnel syndrome, epicondylitis, peritendinitis of the forearm and tenosynovitis in the wrist and fingers (Kurppa et al., 1979; Armstrong et al., 1982; Shiri et al., 2006). A non-optimal design of manual tool handles may increase risks for musculoskeletal disorders but also decrease productivity with the tool (Fransson and Winkel, 1991; Mital and Kilbom, 1992; Blackwell et al., 1999; Peebles and Norris, 2003; Eksioglu, 2011).

The basic functional principle of a manual SG is to squeeze the handle manually while mechanical energy is accumulated in an internal spring. At the bottom end of the handle movement, the accumulated mechanical energy is released into the staple, which hits the target under the gun.

To the best of our knowledge, in all commercially available manual SGs, the force resistance in the handle, when squeezed, is monotonously increased as the gripping distance is decreased (see example for SG1, Fig. 2a), and the maximum is reached immediately before the staple is released when the hand is almost clenched. This more-or-less linear increase is from a technical point of view the most obvious solution.

On the other hand, the force capacity of the human hand shows a force maximum about halfway between maximum gripping width and fully clenched fist forming an inverted u-shape. (Fitzhugh, 1973; Greenberg and Chaffin, 1978; Fransson and Winkel, 1991; Oh and Radwin, 1993; Ruiz–Ruiz et al., 2002; Edgren et al., 2004; Eksioglu, 2004). The grip span at force maximum depends on individual anthropometry (Eksioglu, 2004) and varies between 45 and 70 mm in different studies. Eksioglu (2011) also demonstrated shorter endurance times when gripping at non-optimal gripping width. However, various reference points have been applied for the measurement of grip span, and force has been measured either with parallel handles, with angled handles or with a cylindrical grip. With these various conditions taken together, these data are hard to merge to find the generally applicable optimal characteristics for a staple gun.

Whatever the truly optimal characteristic is, there is a mismatch between the force resistance curve in a conventional SG with linearly increasing force and the corresponding human force capacity

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http://dx.doi.org/10.1016/j.apergo.2015.03.007
0003-6870/

Fig. 1. The assessed staple gun.

curve. This mismatch was identified by the manufacturers of the SGs studied in this work. To improve their tools to better fit the force characteristics of the human hand and to reduce the load on the hand/arm, three new prototypes based on their largest professional manually operated SG (see Fig. 1) were developed. The authors were consulted to evaluate these prototypes. The objective of this study was to assess the prototypes in comparison with a conventional SG in terms of muscular load measured by electromyography (EMG), subjective ratings of tool comfort and free comments by the test subjects regarding practical aspects of the investigated tools.

2. Material, subjects and procedures

2.1. Material

A standard SG (SG1, Isaberg-Rapid, Proline; see Fig. 1) and three prototypes (SG2, SG3 and SG4) were assessed. The exteriors of the prototypes were identical with the standard gun and it was impossible to see any difference. The prototypes were developed by the company (Isaberg-Rapid), which also manufactured the standard SG (SG1). In SG2 and SG3 alternative force characteristics were obtained by small internal mechanical changes of levers and other construction details while SG4 was based on an entirely new technical design. The authors were not involved in this technical development.

The force characteristics of the four guns as a function of gripping distance are shown in Fig. 2a, with a definition of the distance according to Fig. 2b. The force curves were provided by the company and were obtained in a measurement fixture. In SG2 the aim was to reduce the high force peak close to staple release in SG1 while in SG3 a force curve closer to the human hand characteristics with a maximum earlier in the gripping range was intended. It was hard for the technicians to predict the detailed outcome of each technical solution in terms of force characteristics. In SG4 better general efficiency was obtained by new technical solutions, resulting in a generally lowered force graph. The different solutions resulted in minor differences in the point where the major force increase started and the point where the staple is released as can be seen in Fig. 2a.

The manual input energy (E) for the four guns was calculated as the area under the force curves obtained as the sum of the average of two consecutive force samples multiplied by the corresponding distance increment:

$$E = \Sigma(F_i + F_{i+1})/2^*(D_i - D_{i+1}) \quad (J = Nm) \tag{1}$$

where D is the gripping distance, F the force and i is the sample index starting at maximum distance, $D_1 = 80$ mm ($D_i > D_{i+1}$, $i = 1 - 100$). The distance increment was chosen by the company developing the SGs.

The calculated input energies are shown in Table 1.

2.2. Subjects

Twelve experienced professional craftsmen were voluntarily recruited as test subjects. They were all familiar with the professional use of SGs. Their ages ranged from 18 to 56 years, with their average age being 42 years. Their maximal gripping force in the dominant hand was measured according to the procedure described in Section 2.4. The maximal gripping force ranged from 380 to 650 N, and the average gripping force was 500 N.

2.3. Measurement equipment

Grip force. For grip force measurements, a rubber ball vigorimeter (Martin) was used.

EMG. An EMG telemetry system (Mespec 4000, MEGA Electronics Ltd) was used. The raw signals were continuously displayed on an oscilloscope screen for visual quality control. The signals were recorded on a digital DAT-recorder (TEAC RD-101T). Disposable EMG electrodes (Medicotest, Neuroline 72001-K) were used.

2.4. Protocol

Initially the subjects were informed about the aim of the project and that they could leave the tests at any time without notice.

The maximal grip force was measured and stored as the maximal reading of three trials.

EMG surface electrodes were applied on the most prominent bulges of the flexor digitorum superficialis and extensor carpi radialis brevis when clenching the fist. Electrodes were separated by 20 mm and oriented along the muscle fibers. A reference electrode was applied on the lateral epicondyle. EMG measurement quality was visually checked on an oscilloscope at rest, to exclude power-line and other types of interference.

All subjects tested all four SGs once before the real tests. EMG amplitudes were checked and, if necessary, EMG amplification was adjusted for proper signal amplitudes. Before starting the real tests, the subjects were also informed that afterward they would be asked to give free comments regarding their experiences of all the SGs.

The four guns were tested in four possible orders, 1–2–3–4, 2–3–4–1, 3–4–1–2 and 4–1–2–3. The subjects were randomly distributed into one of the four groups, with three subjects in each group.

All subjects fired five staples with each gun into a pine board at their own pace, with a maximum 50 mm of support of the SG from