Influence of disruptive design changes of a hammer drill on user posture and muscle stress - An exploratory study

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Abstract: Repetitive physically demanding tasks, such as operating power tools, can cause work-related musculoskeletal disorders, particularly in the shoulder-arm region. Despite the need for ergonomic product designs, it is often unclear how to adjust power tool design to reduce user stress. This study explores how handle positions and orientations of a hammer drill impact joint angles and muscle activation. An adaptive hammer drill was developed, and three participants performed horizontal drilling tasks. Measurements using motion capture, electromyography, and force sensors revealed that handle configurations affect user posture and muscle activation. Key findings indicate increased handle tilt and angle result in asymmetrical postures and higher muscle activation. In contrast, closer handle positioning promotes balanced force distribution of the left and right sides. Future studies will further investigate these findings with a larger number of subjects and a reduction of noisy factors such as vibration.

Keywords: product ergonomics, user-centered design, power tool, user stress, biomechanics

1. Introduction

Power tool applications such as hammer drilling are often physically intensive due to unfavorable user postures, high exerted forces and additional vibration exposure. Substantially, there is high stress on the musculoskeletal system, particularly in the shoulder-arm region. Prolonged or repetitive use of power tools can contribute to work-related musculoskeletal disorders (WSMDs) such as tendonitis, rotator cuff injuries, and joint pain (Kuok 2022). Although there is an increasing recognition of the need for ergonomic design, power tools continue to be developed primarily on technical performance rather than the user's physical well-being (Vedder & Carey 2005). Some product developers use classical approaches to reduce the user's physical stress, e.g. reducing the power tool's mass or vibration damping. Another approach is using upper limb exoskeletons to support the user in compensating the power tool's mass. Several studies have also examined the physical interface between a handheld device and the user. Parameters such as handle geometry, e.g. diameter and orientation, can affect grip force, wrist angle, and forearm muscle activation (Björing et al. 2007; McGory et al. 2007; Lin et al. 2007). The problem is that the parameter space is large, and it remains unclear which changes in handle position and orientation impact user posture (joint angles) and muscle stress (muscle activation) of the shoulder-arm system. To address this problem, the following research question was formulated:

> *How do variations in handle position and orientation of an adaptive hammer drill affect the shoulder-arm system's joint angles and muscle activation?*

2. Material and Methods

To answer this research question, an exploratory laboratory study was conducted. First, an adaptive hammer drill was developed based on a Hilti TE 2 (Hilti AG, Schaan, Liechtenstein) to systematically adjust the positions and orientations of the main handle (MH) and side handle (SH). Figure 1 shows the developed hammer drill in its default configuration, which was based on the original hammer drill. Both handles consist of two PLA-printed handle halves with two single-axis piezo-electric force transducers Kistler 9001 A (Kistler Instrumente AG, Winterthur, Schweiz) in between. The separation plane was always oriented orthogonally to the drilling direction based on the definitions of DIN EN ISO 10819:2022-12 (DIN EN ISO 10819:2022-12). Each handle was connected to the hammer drill by 1) a three-axis piezo-electric force transducer Kistler 9011 A measuring interaction forces between user and power tool, and 2) a locking joint allowing a tilt of the handles in 7.5 ° steps. The trigger control was removed from the power tool via a cable extension for external operation by a study supervisor. Figure 2 shows the handle configurations used in the study.

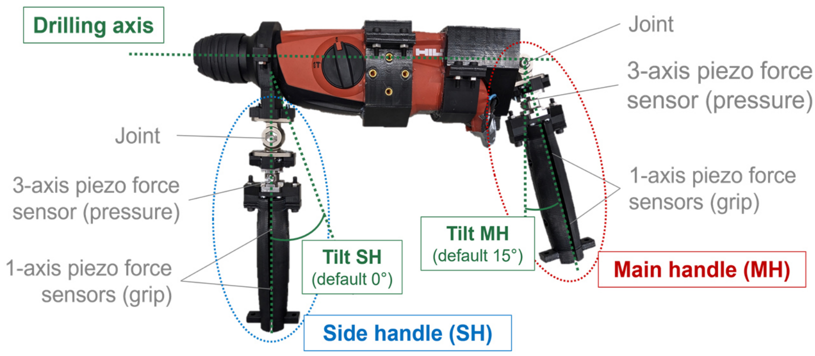

***Figure 1**: Adaptive hammer drill in the default configuration; main handle (MH) and side handle (SH) adjustable in position and orientation; integrated force sensors allow capturing interaction force at the handles.*

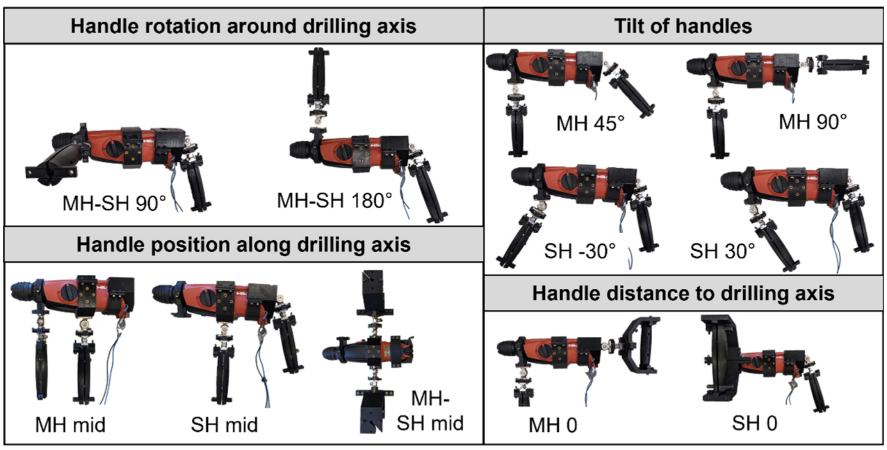

***Figure 2**: Handle configurations of adaptive hammer drill set in the study, with MH: main handle, SH: side handle.*

The developed adaptive hammer drill was used to conduct a laboratory study with three participants (20-30 years old, right-handed, one male, two female) performing a horizontal drilling task. To record muscle activation, electrode heads of four Delsys Trigno Duo and two Quattro electromyography (EMG) sensors (Delsys Inc., Natick, MA, USA) were placed on the left and right anterior, lateral, and posterior deltoid (shoulder), upper trapezius (neck), biceps brachii, triceps brachii long head (upper arm), extensor carpi, and flexor carpi (lower arm). The sensor placement and measurement preparation were conducted following the SENIAM guidelines (Hermens et al. 1999). Muscle-specific maximum voluntary contraction (MVC) tests were performed twice per muscle. Full-body posture was measured using the IMU motion capture system (XSens Adwina, Movella, Henderson, NV, USA). 17 sensors were placed on defined body segments of the test subjects and then calibrated.

The drilling tests were performed based on the setup in Figure 3. The participants drilled horizontally in a vertical concrete wall using the adaptive hammer drill (the right hand was placed at MH, the left at SH), varying between 12 handle configurations (s. Figure 2) in a randomized order. Each configuration was repeated three times. The subjects were standing on a force measuring plate (BP600900-1000, AMTI, Watertown, MA, USA), which enabled the measurement of the push force. Using digital user feedback, the subjects had to maintain an overall push force of 90 N during the drilling measurements. Each drilling measurement was timed (~10 s), and a study supervisor externally triggered the hammer drill. The working height and distance to the concrete wall were customized to the participants' body dimensions. Throughout the drilling measurements, motion capture data was acquired at a rate of 60 Hz, EMG data at 2222 Hz (Quattro Sensors) and 2148 Hz (Duo Sensors), force data of grip and push forces on both handles and ground reaction forces at 5000 Hz. EMG data was onboard bandpass filtered with 20-450 Hz. We also measured the power tool’s vibration at a rate of 5000 Hz using two PCB 356A02 acceleration sensors (PCB Piezotronics, Depew, NY, USA) attached to the handles. All data was cut based on exceeding 90 % of the defined push force. The mean joint angles and handle forces over time and the RMS of the EMG data were calculated for each measurement. To determine muscle activation as a percentage value, RMS of the MVC measurements were utilized for EMG normalization. The joint angles, handle forces, and muscle activation were averaged across all subjects for each configuration. Data post-processing was performed using Matlab (R2024b, MathWorks, Matick, MA, USA).

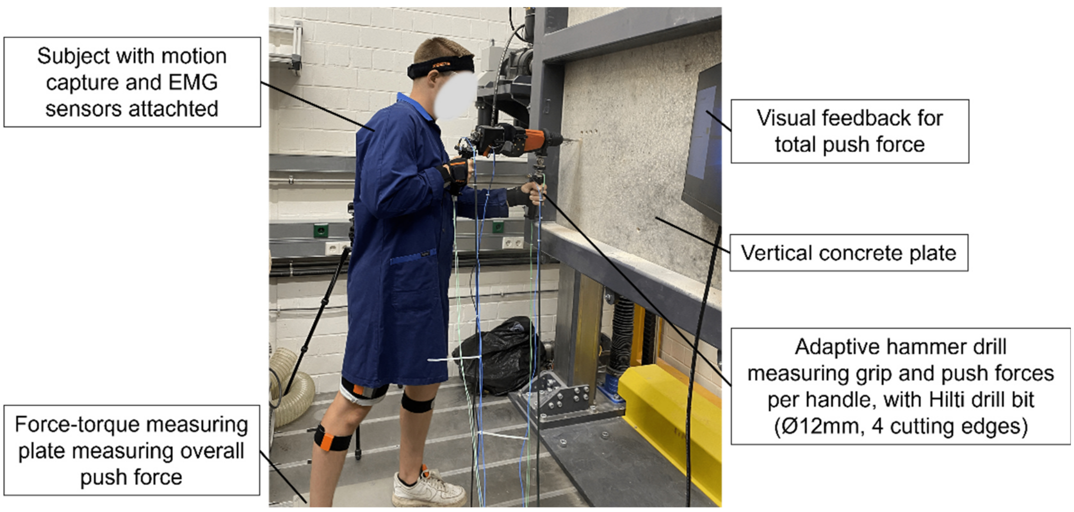

***Figure 3**: Study setup of horizontal drilling with the example of default configuration.*

3. Results

This section presents the influence of handle positions and orientations of an adaptive hammer drill on body joint angles and muscle activation. The key results of shoulder positioning and muscle activation are shown in Figure 4. Further study results can be seen in Sutschet et al. (2025).

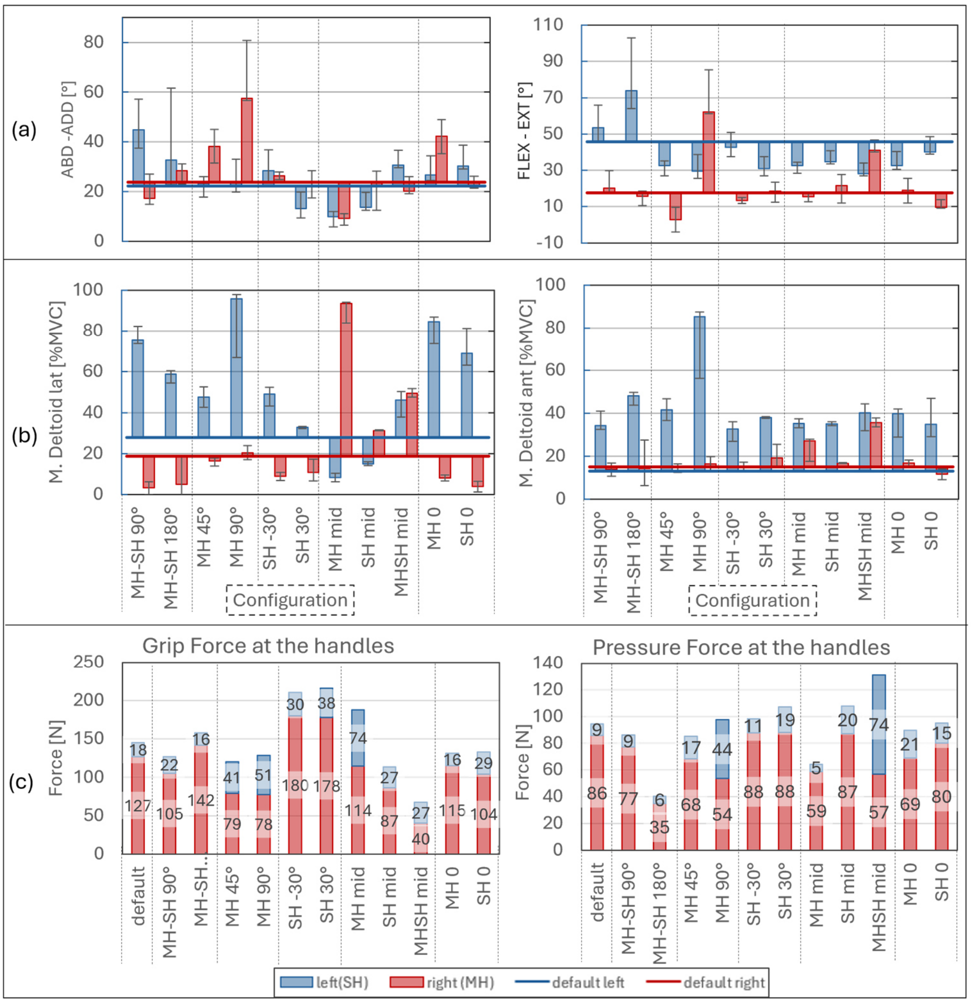

Figure 4: *Deviations of the shoulder joint angles (a) and muscle activation M. deltoideus (b) to the values of the default configuration for the left (blue) and right (red) shoulder-arm system. (c) Force distribution between the main (red) and side (blue) handle for the grip and push forces over all configurations. Median values and 1st & 3rd quartile of n=9 data points (3 subjects à 3 repetitions).*

Angle between handles around the drilling axis: Increasing the angle between the MH and SH resulted in notable positional changes, particularly affecting the shoulder on the left side. A greater angle led to a more asymmetrical posture, characterized by increased shoulder abduction (Abd) and flexion (Flex) on the left side. These biomechanical adjustments were accompanied by heightened muscle activation, specifically in the lateral deltoid on the left side. While the activation of the trapezius muscle on the right side increases *(17%MVC).*

Tilt of handles: Adjustments to the tilt of the handles showed effects on the respecttive side in both joint angles and muscle activation. A greater tilt of the MH led to increased wrist adduction (Add) *(-23°)* and shoulder abduction on the right side, alongside muscle activation of the lateral deltoid increases on the right and left sides, and the right forearm muscle activation increases. Lowering the tilt of the SH towards the tip led to less wrist abduction *(27° Abd to 7° Add)* and reduced muscle activation of the flexor carpi (< *5%MVC*). Other notable changes in joint angles or muscle activation compared to the default configuration could not be made.

Handle position along the drilling axis: Changes in the longitudinal position of the MH produced distinct biomechanical effects. A forward shift of the MH increased muscle activation of the lateral deltoid (+*75%MVC*), trapezius (*+46%MVC*), and extensor carpi on the right side (*+37%MVC*). Concurrently, the contralateral side's activation of the anterior deltoid and extensor carpi (+66%MVC) increases. Adjustments to the right arm position were also observed, including less shoulder abduction, reduced elbow flexion, and increased wrist abduction *(+12°)*. Repositioning the SH along the drill axis did not result in notable changes in joint angles or muscle activation patterns. Positioning both handles closer together and at the side of the hammer drill (MH-SH mid) resulted in a slight increase of the upper and lower arm muscles on both sides, more on the right than the left.

Handle position along handle axis: When the MH was positioned at the midpoint of the drill, there was an increase in shoulder and wrist abduction on the right side. Wrist extension increased on both sides under both minimum-distance condition, and the activation of the forearm muscles and the lateral deltoid.

4. Discussion

This paper examines the influence of handle positions and orientations on joint angles and muscle activation of the right and left shoulder-arm systems. In general, different handle configurations affect user posture and muscle activation, especially the tilt of the main handle and the distance between handles along the drilling axis. Changes in muscle activation can be explained by a change in the corresponding joint angle of the muscle, a change in grip force, or a change in the distribution of the push force at the handles. In the following, the observed relations are formulated as design hypotheses:

Angle between handles: When increasing the angle between the handles, the user adapts the shoulder-arm position of the left side, which leads to higher shoulder muscle activation on the left side.

Tilt of handles: When increasing the MH tilt, the muscle activation of the right shoulder and right lower arm muscles increases due to changes in the shoulder-arm position. When increasing the MH tilt, the muscle activation of the left shoulder and lower arm increases due to a shift of the push and grip force to the side handle. When changing the SH tilt, there are almost no changes in joint angles and muscle activation.

Handle position along the drilling axis: When positioning the main handle closer to the side handle along the drilling axis, lateral shoulder, and forearm muscle activation increases due to position changes of the right shoulder-arm system and a shift of the grip force to the left side. In contrast, there are almost no changes when shifting the SH closer to MH. Positioning both handles closer together (minimum distance) and at the side of the hammer drill results in higher activation of the upper and lower arm muscles on the right than on the left side due to a more symmetrical posture and a more balanced force distribution and load.

Handle position along handle axis: When positioning one handle at the side of the hammer drill, wrist extension and forearm muscle increase due to a change of the handle orientation.

Conclusion: It is challenging to identify handle configurations that overall minimize user stress, as a decrease in activation of one muscle can lead to an increase in another. An evaluation score could help product developers consider multiple ergonomic factors in the future to enhance the ergonomics of power tools.

Limitations: The number of subjects was limited to three due to the time-intensive preparations and measurements. Future studies will reduce the number of investigated handle configurations to allow a larger number of subjects.

Moreover, vibration affects EMG signal amplitudes (Fratini et al. 2009), which poses a challenge, as MVC measurements were taken without vibration. This could contribute to partially higher EMG values during drilling than MVC data, e.g. biceps muscle activation. Additionally, future studies should aim to eliminate or investigate vibration-induced noise.

Some joint angles and muscle activation showed partially considerable scattering. An individual positioning and handling of unusual hammer drill configurations probably caused this. Future investigations could also assess the joint angles and muscle activation regarding their suitability and correlations to reduce the parameters and thus the effort for a comprehensive ergonomic assessment of a power tool design.

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