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A biomechanical assessment of hand/arm force with pneumatic nail gun actuation systems

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ABSTRACT

A biomechanical model is presented to estimate user hand/arm force exertion with two pneumatic nail gun trigger systems. The sequential actuation trigger (SAT) is safer than the contact actuation trigger (CAT) but increases the user's exertion of force because the trigger must be actuated after the safety tip is held pressed against the workpiece. Time integrated hand force was calculated for a single user based on direct measurement of nail gun tip force against the workpiece (tip contact) and from estimated force to support the tool weight during transfer between nails and during idle holding. The model shows that hand/arm force increases when nailing with the SAT (relative to CAT) and with a vertically-oriented workpiece (relative to horizontal). Expressed per nail fired, the user exerted 0.13 Ns (horizontal orientation) and 2.88 Ns (vertical orientation) integrated hand force during tip contact with CAT compared to 26.15 Ns (horizontal) and 46.08 Ns (vertical) with SAT. Depending upon idle holding duration, integrated hand force during tip contact was estimated to have been 1–3% of 48–132 Ns total hand force with CAT and 21–44% of 83–167 Ns total hand force with SAT (average of horizontal and vertical orientations). Based on standard time allowances from work measurement systems it is proposed that efficient application of hand force during tip contact with SAT can reduce this contribution to 6–15% of 55–139 Ns total hand force. The model is useful for considering differences in hand/arm force exertion between the SAT and CAT systems

Relevance to industry: This paper presents a model of hand/arm force associated with two types of pneumatic nail gun actuation (trigger) systems. The model clarifies differences in user force exertion with the sequential actuation and contact actuation triggers to inform nail gun trigger selection decisions.

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1. Background

In the period of 2001–2005 occupational use of pneumatic nail guns resulted in 22,000 emergency room visits per year in the U.S. (MMWR, 2007). Approximately two-thirds of these traumatic injuries were to the upper extremities, hand, and fingers (MMWR, 2007) and were relatively minor in terms of treatment, outcomes, and lost time. However, more serious injuries, and even fatalities, have been reported (CPSC, 2002a). The ubiquitous use of the framing nail gun (which discharges a larger fastener) in the residential construction trade, and the increasing prevalence of their use among consumers make these larger framing nail guns of greatest concern in this class of tools.

In addition to a finger trigger, pneumatic nail guns (PNGs) for wood framing have a second operating control consisting of a spring-loaded workpiece contact ("safety tip") that must physically engage by pressing against the workpiece. This safety tip prevents a nail from acting as an airborne projectile. PNG actuation system scan be broadly classified into two designs based on whether the controls must be operated in a sequence-dependent order. The contact actuation trigger (CAT) design allows the workpiece contact and trigger to be activated in either order to discharge a nail and the trigger does not need to be released for individual nails. Common practice with the CAT is "bump firing" in which the user holds the trigger depressed and only the single action of "bumping" (pressing) the workpiece safety tip against the workpiece is required to discharge an individual nail. The safety concerns with such a design have been well documented (Lipscomb et al., 2003, 2008a). When the trigger is held depressed an inadvertent "bump" against the workpiece contact of the tool can, and often does, discharge a nail.

The full sequential actuation trigger (SAT) design requires a sequence-dependent activation of the controls. The safety tip must be pressed against the workpiece *before* the finger trigger is activated to discharge a nail. Additionally, both controls must be released prior to repeating the sequence for firing of another nail. The safety benefit of the SAT design is the prevention of trauma due

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to unintended nail discharge and the prevention of double fire, where the nail gun recoil results in an inadvertent second contact with the tip against the workpiece.

A common perception in the residential construction industry is that CAT PNGs increase productivity and result in "easier" use than SAT PNGs. In spite of the fact that the SAT is a demonstrably *safer* trigger (Lipscomb et al., 2003; 2008a) significant barriers to adoption of the SAT appear to be the perceived reduction in productivity and the perceived increase in physical demands of the SAT because of the two-stage process of engaging the safety tip followed by trigger press.

The purpose of this paper is to present a basic model to describe the user input of force required by both SAT and CAT systems, in two common nailing orientations, and to estimate the differences in relative contribution of these trigger actuation systems to the total hand force exerted in use of the tool. The model simplifies nail gun use to a basic mechanical system with external forces to support the mass of the tool when held idly and to apply force on the workpiece contact (safety tip) to actuate the tool. The dynamics associated with movement of the nail gun throughout the workspace are simplified in the model because there are countless nuances in work practice and user technique affecting the dynamics of the PNG as it is transferred into position prior to making tip contact with the workpiece. The model does account for the effect of recoil energy unloading the mass of the tool supported by the user in the transfer of the nail gun between nail locations in repetitive nailing on a horizontal workpiece (e.g. sheathing, flooring, or "flatwork").

2. Method

2.1. General model of hand force

Hand force associated with PNG use is considered in the framework shown in Fig. 1. Exertion of force results from the *holding nail gun idle* and *nailing* task elements. Other activities in residential construction that do not involve interface with the nail gun, are not considered. The activity of *nailing* is comprised of two task elements: *tip contact*, the action of discharging a nail while the safety tip of the nail gun is pressed against the workpiece, and *transfer between nails*, the action of moving the nail gun to the next nail location during which time there is no contact between the nail gun and workpiece and the mass of the PNG is supported by the user. *Holding nail gun idle* encompasses all other aspects of manual interface with the tool. It may not necessarily represent "idleness" of the worker, but it is intended to represent idleness of the hand supporting the mass of the nail gun where the force exerted is equivalent to the weight of the tool. In a time and motion study context this could be considered an "unavoidable delay" for the hand holding the nail gun, while the opposite hand is positioning another object, such as a workpiece. It could also represent both hands being inactive if the worker is walking between locations on the worksite, but not in the process of nailing (also unavoidable delay). The nail gun can also be held idly by the worker in an avoidable delay situation.

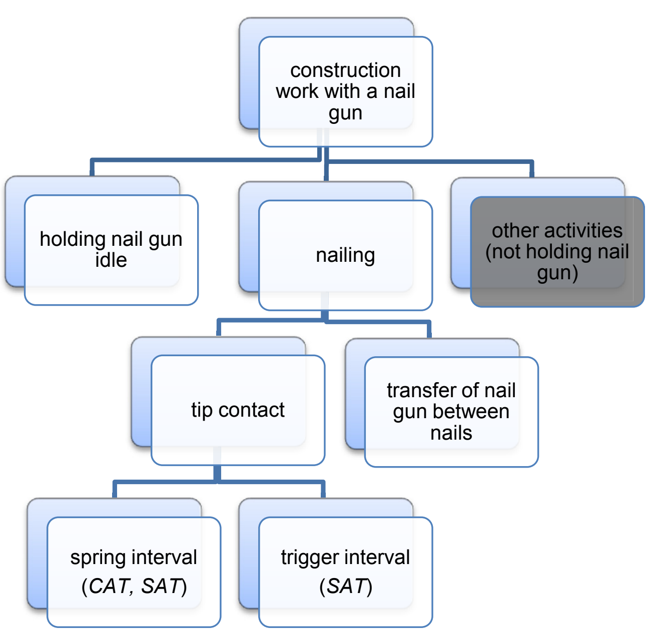

Fig. 1. Framework for evaluating hand force with PNG use. Activities for which the nail gun is not held in the hand are not considered.

2.1.1. Holding nail gun idle

When *holding nail gun idle* it is assumed that the exertion of hand force by the user is equivalent to the tool weight plus 6.7 N of additional load from the air hose. Force plate measurements of standing while holding framing nail guns of approximately 35.5 N in weight, half-filled with nails, connected to a supply hose confirm a 42.2 N load. Cumulative force over the holding time is simply equal to the weight of the nail gun and hose (42.2 N) multiplied by the duration of holding time. The activity of loading the nail gun is considered *holding the gun idle* because the primary exertion is to support the tool weight. When holding the nail gun idle exertion by the user is assumed to be independent of the actuation system. Estimates for idle nail gun holding time per nail fired are presented in Appendix A and suggest that a range of 0.3–1.5 s idle holding time per nail is consistent with work practices.

2.1.2. Transfer of nail gun between nails

Hand force in the transfer of the nail gun between nailing locations was simplified by assuming that support of the nail gun mass against gravity for the duration of transfer represented the primary load in the transfer of the tool. Cumulative load was calculated by multiplying transfer time by the weight transferred. We differentiated between movement of the nail gun with a vertically-oriented workpiece and horizontally-oriented workpiece (flat nailing), because in the latter orientation the external input of energy from the nail fire and resulting recoil serves to "assist" the user in moving the nail gun away from the workpiece (opposite to the gravitational vector) and creates an unloading of the tool weight from the user. For nailing a vertically-oriented workpiece (such as "through-nailing" studs to plates in the framing of a wall) the recoil of the nail gun is directionally perpendicular to the gravity vector and makes no contribution to unloading the mass of the tool supported by the user. The reduction in load due to recoil energy was estimated in experimental pilot testing (described in Appendix B) and applied in the calculation of cumulative hand force during nail gun transfer in horizontal (flat) nailing.

2.1.3. Tip contact

For each nail fired tip contact is defined as the time between initial safety tip contact with the workpiece and ends with nail fire, when the recoil energy moves the safety tip off the workpiece (Fig. 2). Hand force applied to the nail gun overcomes the resistance in the safety tip mechanism, which includes a spring-loaded sliding workpiece contact. The interval during which the spring is being compressed after the safety tip makes contact is referred to as the *spring interval*. With a CAT, the trigger can be held depressed *before* the safety tip makes contact with the workpiece and the nail gun discharges a nail at the instant the spring resistance is overcome. With the SAT the trigger must be activated *after* the spring interval and the user must push the tool against the workpiece with a force