Applied Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uaoh20

Ergonomics of Rebar Tying

Awwad J. Dababneh & Thomas R. Waters

Published online: 30 Nov 2010.

To cite this article: Awwad J. Dababneh & Thomas R. Waters (2000) Ergonomics of Rebar Tying, Applied Occupational and Environmental Hygiene, 15:10, 721-727

To link to this article: http://dx.doi.org/10.1080/10473220050129329

Applied Occupational and Environmental Hygiene
Volume 15(10): 721–727, 2000
1047-322X/00 $12.00 + .00

Ergonomics

Ergonomics of Rebar Tying

Scott Schneider, Column Editor

Reported by Awwad J. Dababneh,* and Thomas R. Waters

Concrete is a versatile building material and concrete work is a major part of most construction projects, such as foundations, bridges, roads, and airport runways. In order to improve the strength characteristics of concrete, it is reinforced with iron bars. These iron bars are commonly known as "rebar." Rebar rods are tied together and placed within the structure's form prior to pouring the concrete (see Figure 2c). On the construction site, rebar work is commonly known as rod-busting, and workers who do the rod-busting are called rod-busters or rod-men. In this article, the term rebar workers is used to refer to workers who do rebar work.

In recent years, The National Institute for Occupational Safety and Health (NIOSH) and the Center to Protect Workers' Rights (CPWR) have expressed a growing concern about the risk of musculoskeletal disorders (MSDs) associated with rebar tying.[1,2,3] However, the ergonomic risk factors and injuries related to this type of work are yet to be evaluated. In the 1970s, research studies from Europe identified rod work as a hazardous job that resulted in a high rate of back injuries.[4,5] These studies also identified heavy lifting, forceful pulling, and continuous back bending as risk factors. Depending on the work situation, rebar workers may spend 66 percent of their workday with their back flexed.[5]

The U.S. Bureau of Labor Statistics (BLS) estimates that 21,990 rebar workers were employed in the United States in 1997.[6] A review of the BLS data shows that 5741 nonfatal occupational injuries and illnesses involving days away from work were reported during the same year.[7–13] None of the injuries or illnesses were classified as repetitive motion injuries, however 2052 were classified as overexertion injuries. Injuries were classified according to the body part affected as follows: 1461 injuries to the upper extremities, 1262 injuries to the lower extremities, 1186 injuries to the back, and 290 to the shoulders.[7–13] It is not possible to link these injuries to a specific task such as tying, because there are other high-risk tasks that rebar workers perform, such as lifting and climbing vertical walls.

The most common task in rod work is tying rods. In most tying methods, a metal wire is used to tie rebar rods together. Workers usually wear gloves for protection from hot or cold rods and from getting cut by metal spur and tie wires. There are different types of wire ties depending on the number of wire strands used and the basic shape of the tie (simple loop or more complex).[14] As with most hand tools, rebar tying tools may subject workers to physical risk factors that may cause injuries to their upper extremities and back.[15] In this investigation, rebar workers were observed to spend 80 percent of their workday tying rebar with wires. Traditional tying tools, such as pliers and the pigtail, require the worker to bend over to be able to reach the ground level and carry out the tying. New and different tools were designed to enable rebar workers to do the work without bending. As early as 1959, U.S. patent literature showed powered machines for tying rebar.[16] However, it was only in the last two years that powered rebar tying tools have been introduced in the U.S. market. Manufacturers of such tools promise faster operation and increased comfort for workers. Nevertheless, no studies have been reported that would confirm such claims. It is worth mentioning that we were unable to locate any American-made powered rebar tying machines; most are made in either Japan or Europe. Thus, studies published in non-English languages may exist.

Methods for Tying Rebar

Five basic methods for rebar tying or connecting were identified. They are:

1. Pigtail. In this method the worker uses a precut wire and a twisting tool that looks like a pig's tail.
2. Pliers. This method uses a spool of wire and pliers.
3. Support chairs, which uses plastic chairs and connectors.[17]
4. Rebar stapler, where wire clips or plastic connectors are applied with a stapler-like tool.[18]
5. Powered tying tools.[16,19,20,21]

Pigtail

This method is also known as the "Yo Yos," because workers use precut pieces of wire that are shaped like the letter U. The worker places the precut piece of wire around the rebar and then twists the two ends of the wire using a tool that looks like a pig's tail. A picture of this tool is shown in Figure 1. Workers and contractors interviewed during this investigation reported that the pigtail method is the second most popular among U.S. construction workers. Novice and occasional rebar workers prefer this method, but full time experienced rebar workers prefer the pliers and wire spool method. Experienced workers claim that when using pliers they tie faster than they would when using the pigtail.

*This work was performed while Dr. Dababneh held a National Research Council fellowship at NIOSH.

FIGURE 1
Pigtail twisting tool used in rebar wire tying.

Pliers

Workers and contractors interviewed for this investigation reported that the pliers method is the most common among U.S. rebar workers. The tools used in this method consist of linesman pliers, diagonal cutter, and a wire spool. The linesman pliers are used to cut, hold, and twist the wire. The diagonal cutter is used to undo a tie, or to cut the wires holding a new wire coil once it is placed in the spool. The wire spool is attached to a belt that the worker would wear on his or her waist. The wire spool holds a 3.5-pound. (16–16.5 Ga.) wire coil. The worker pulls and cuts a length of wire from the spool, then wraps it around the rebar and finishes the tie by holding and twisting the two ends of the wire using the linesman pliers. Figure 2 shows the tools used in this method.

Support Chairs

Rebar support chairs are designed for use on grade or precast applications. The main function of rebar chairs (or spacers as they are commonly known) is to hold the rebar above the ground creating a space underneath it (see Figure 3). Depending on size, the rebar is attached to the spacer by either a snap-on action or by a wire tie. By using snap-on rebar chairs (for small rebar; U.S. #3 through #6), manufacturers claim that wire tying could be eliminated. On the construction site, it was discovered that the use of support chairs as spacers are common. However, no evidence was found to show that rebar chairs eliminated the need for wire tying.

Rebar Stapler

Similar to using rebar chairs, rebar staplers are used only on horizontal applications. It places a wire or a plastic clip on two rebar rods crossing each other using an applicator tool that is similar in function to a paper stapler. Figure 4 shows two models of this tool and a worker using it. Ergonomic benefits of this method include elimination of back bending and wrist twisting. This method is used in Europe, but not in the United States. It is not possible to use the European clips and rebar staplers in the United States because of differences in the standard sizing of rebar. In the United States, rebar is manufactured in diameters that are multiples of 1/8 inch, and are identified by the number of 1/8 inch units in the diameter. For example, rebar #4 has a diameter of 1/2 inch (4/8 = 1/2). Rebar in Europe is manufactured in diameters that are multiples of one millimeter, and are identified by the number of one

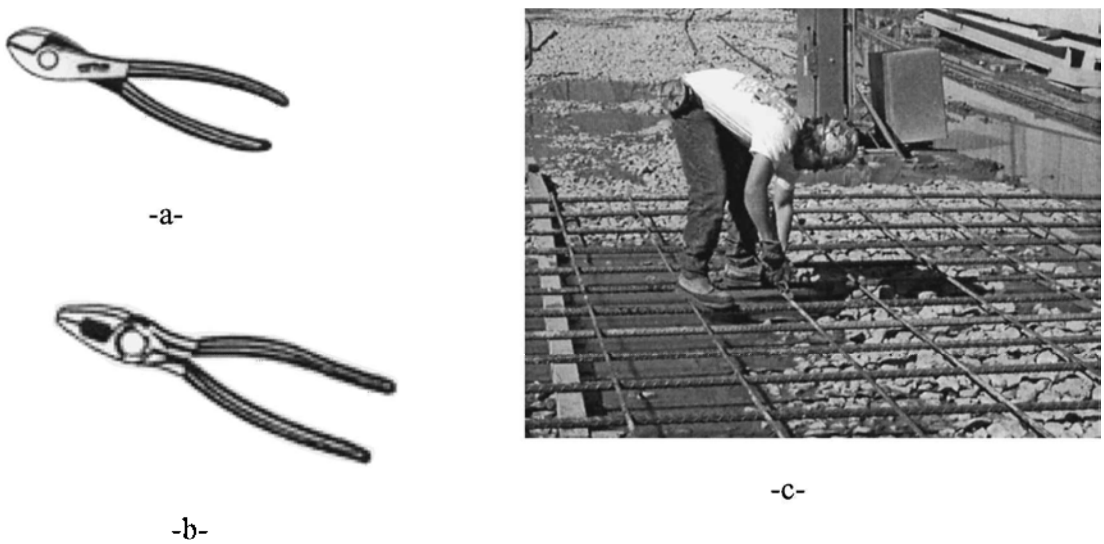


FIGURE 2
(a) Diagonal cutter, (b) Linesman pliers, (c) Wire spool on worker's waist.

-a- -b-

FIGURE 3
(a) Snap-on chair for small rebar, (b) Support chairs for large rebar.

millimeters units in the diameter. For example, rebar #13 has a diameter of 13 mm. A clip that is designed to be used with #13 rebar in Europe would be too big for the equivalent #4 rebar in the United States (13 mm > 1/2 inch).

Power Tying Tools

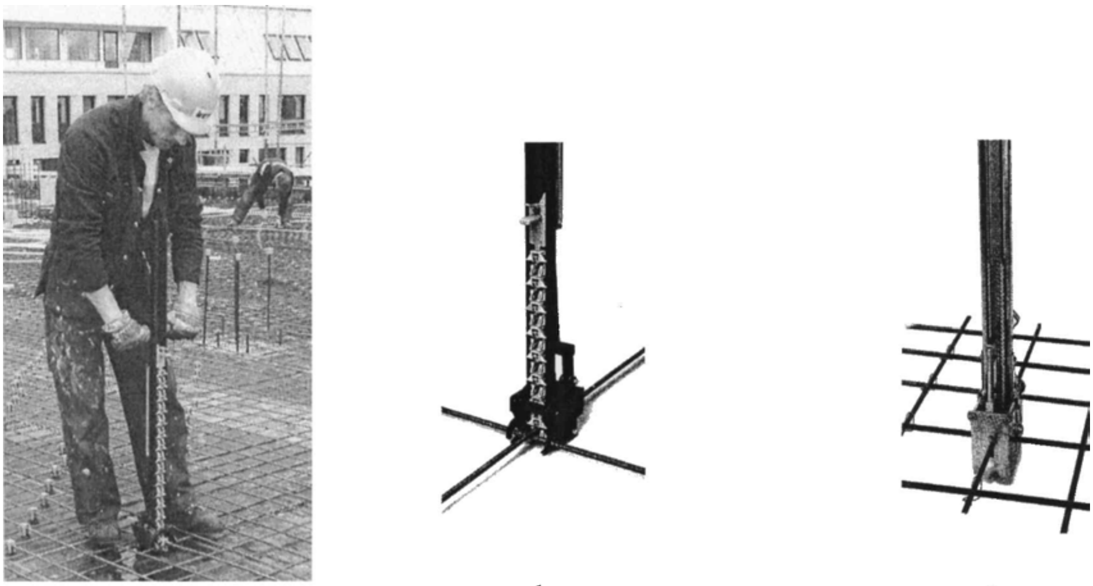
Currently, there are four models of powered rebar tying tools (see Figure 5). They are:

- RE-BAR-TIER, manufactured in Japan and distributed in the United States by MAX USA Corp., Garden City, New York.
- U-Tier (two models), manufactured in Japan and distributed in the United States by Southland International, Chicago Heights, Illinois.
- U-BINDER, manufactured in Japan and not available in the United States.

They all function similarly. The jaws of the powered tools are placed around the intersecting segments of rebar rods and a trigger is depressed, which causes the tool to automatically feed the wire around the bars and twist it. The three tools are powered by either rechargeable batteries or by plugging directly into an electrical outlet. All models use wire coils that are specially designed for use with each tool.

Physical Risk Factors

Physical risk factors are those conditions imposed on the worker by either the work situation or by the tools used that would put the worker at risk of MSDs. To assess the physical risk factors associated with the pigtail, pliers, and plastic rebar chair methods, five experienced workers were observed and videotaped. The videotape was analyzed to determine the type of movements, speed, and working posture required to perform the various tasks. Automatic tying machines were inspected and a manufacturer-supplied videotape of workers using automatic rebar tying machines was used to assess ergonomic characteristics of the automatic rebar tying method. Because the rebar stapler method is not used in the United States,



-a- -b- -c-

FIGURE 4
(a) Worker using stapler-like tool to join rebar, (b) Model of the tool that uses plastic connectors, (c) Model of the tool that uses wire clips.

our ergonomic evaluation was based on product literature and a description of the tools obtained from the manufacturer. In general, the physical risk factors identified in rebar tying may be categorized as follows:

- Repetitive motion (wrist twisting, stooping);
- Awkward posture (ulnar deviation and flexion of the wrist, back bending, and excessive reach);
- Forceful exertion (carrying heavy tools, pretension of wire by tapping, and excessive operating force); and
- Vibration and kickback forces when using power tool.

The exposure to the above risk factors may vary depending not only on the method and tool used, but also on whether the work is vertical (walls), or horizontal (floors, slabs, and foundation). When doing vertical work, workers may climb on the rebar structure to reach high levels where they would be required (by OSHA) to wear fall protection body harnesses and secure themselves to fixed structures that are strong enough to hold their weight. Anchored with the body harness, workers tend to reach excessively to do as much work as they can reach before they unhook and move their anchor point. In this case, excessive reaching would also be a significant physical risk factor.

Physical Risk Factors When Tying Wires with the Pigtail Tool

The pigtail method may be used in both horizontal and vertical work situations. Workers may do 400–600 ties per workday. Physical risk factors include bending at the back or excessive bending and twisting at the wrists. Close examination of the tying process using this method revealed that workers might also exert repetitive forceful pulling. After the first two twists of the wire, the worker would pull on the wire to tighten it around the rebar rods, and then finish the tie by further twisting of the wire. Depending upon how forceful the worker would pull on the wire, repetitive forceful pulling may be considered a significant physical risk factor.

Physical Risk Factors When Tying Wires with Pliers

As with the pigtail method, this method may be used in both horizontal and vertical work situations. Workers may do 400–600 ties per workday. Physical risk factors include back bending and excessive bending and twisting at the wrists. Close examination of this tying method revealed that workers would use two methods to tighten the wire around the rods. The first method is to hold both ends of the wire using the pliers and pull before twisting. In the second method, the worker would hold the two ends of the wire using the pliers and do a hammering-like motion. Either method, when performed 400–600 times per day, is considered a significant physical risk factor.

Physical Risk Factors When Tying Wires with a Wire Spool

In this method, the worker would pull the wire from the spool and cut it using the linesman pliers. The required effort to cut the wire may vary depending upon the condition of the cutting jaws of the pliers and thickness and toughness of the wire. Wire cutting that requires high force would be a significant risk factor for MSDs.

Physical Risk Factors When Using Rebar Chairs

Rebar chairs are only used in horizontal work situations. Use of rebar chairs

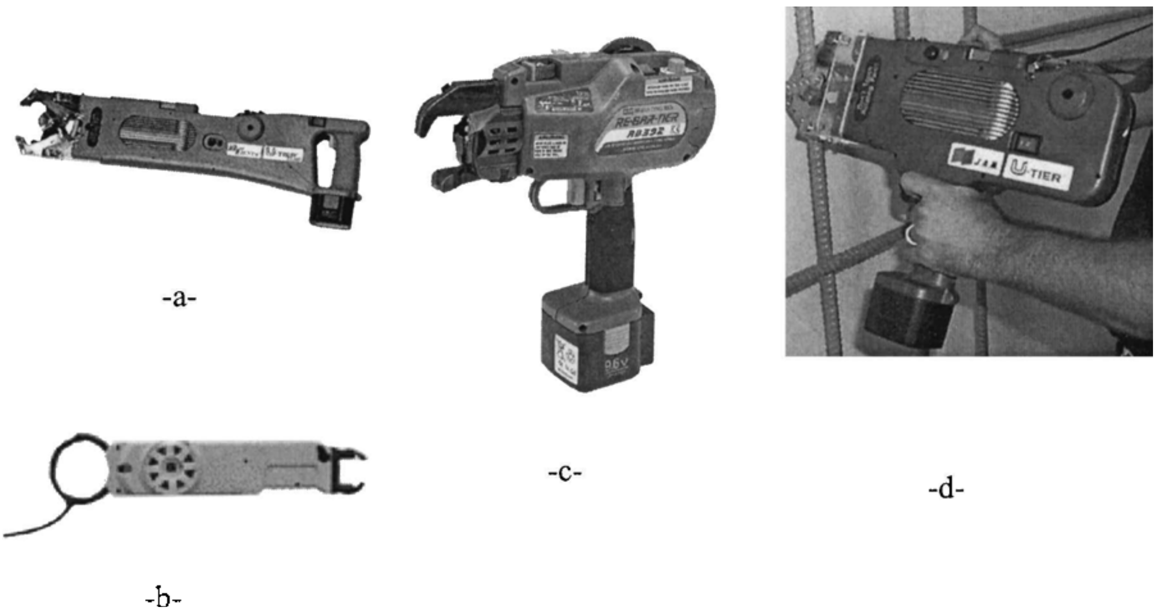


FIGURE 5
Power tying machines (a & d) U-TIER, (b) U-BINDER, (c) MAX RE-BAR-TIER.

would at least reduce the number of ties needed to finish the job, and, thus, would reduce wrist twisting. However, workers would still need to bend at the back to place chairs under the rebar.

Physical Risk Factors When Using the Rebar Stapler

This method is only used in horizontal work situations. It eliminates most of the physical risk factors that are associated with the previous methods. There is no need for the worker to bend or twist. Furthermore, the handles of the tool are oriented in a way that will allow the worker to keep straight wrists. However, the tool weight is high (19 pounds empty), and it requires a downward push force to operate, which, in turn, may create excessive moments on the joints of the upper extremities, and may cause rapid fatiguing and discomfort.

Physical Risk Factors When Using Powered Rebar Tying Tools

Properly designed powered tying tools may be the best ergonomic solution for rebar tying. Extended tool-body design may be used to eliminate the need for stooping when working on a horizontal platform. Also, tools with a pistol grip would allow workers to tie vertical rebar while keeping their wrist straight. However, some risk factors that are unique to all powered tools would still be present. In general, powered tools are heavier than non-powered tools, which may subject the joints of the upper extremities to excessive moments that, in turn, may cause rapid onset of fatigue and discomfort. Moreover, powered tools are generally associated with vibration during operation, and with high kickback forces on the hand at the end of the operation cycle.[15] Vibration and kickback characteristics of a power tool may change significantly as the tool ages. Newer and well-maintained powered tools generate less vibration and reduced kickback forces on the operator's hand. Thus, when evaluating powered tools, it is important to consider the whole life cycle of the tool.

Other Considerations in the Selection of a Rebar Tying Method

Range of Usability

Using pliers or the pigtail methods is versatile and can be used to tie any size of rebar in both horizontal and vertical work situations. In comparison, the rebar chairs and the rebar stapler methods are used only on horizontal platforms, and can be used only with certain rebar sizes. The rebar stapler connects rods with diameters from 8 mm to 16 mm, and the snap-on rebar chairs are only available for sizes of 10 mm to 19 mm. Moreover, these two methods require a size-match between connector and rods. Rebar chairs that are larger than 19 mm (U.S. #6) would need to be tied to rebar with wires.

Power tying tools are also limited in their range of operation; at most they would handle 19 mm rods (U.S. #6). This implies that on projects such as highways, bridges, airports, and other large structures where rods greater than 19 mm in diameter are used, workers will have to use either the pliers or the pigtail method.

Other than tying rebar to rebar, workers may be required to tie spacers, or cables to a rebar mesh. Powered tying machines may not be able to do these types of ties, and workers will have to use the pliers or pigtail methods. Thus, workers may favor the traditional do-it-all methods over other methods with limited range of usability.

Maintainability

Maintainability of tools becomes an important issue when using powered tools. Periodic maintenance is needed because some parts wear out and need to be replaced.[16,19,20] The frequency of repair depends on the frequency of use and on environmental factors that may affect the tool, such as dust, hot or cold weather, humidity, and wet work environment.

In an interview, users familiar with tools reported that the wire would get stuck inside the tool and it would take a significant amount of time to get it repaired. In some cases, this made workers give up on using the powered tying tool and go back to the traditional method.

Cost

The evaluation of the total cost of using any rebar tying method should include workers' productivity, and the impact on the well-being of rebar workers. Unfortunately, no studies were found that simultaneously addressed workers' productivity and well-being. Therefore, it is not feasible to quantify the total cost of each rebar tying method. However, the initial investment, running cost, and the cost to maintain the tools can be evaluated. Also their impacts can be predicted.

The cost of the traditional tools generally does not exceed $50 per worker, but the average cost of a powered tying machine is around $2000. Powered tying machines can only use special wire coils that are produced by the same tool manufacturer. The cost of the wire needed to do 1000 ties using the traditional methods is estimated at $11.26, and between $7.69 and $16.93 using powered tying machines. Although both traditional and automated wire tying methods have similar wire costs, other issues such as market availability and the lead time between placing an order and receiving a shipment, may also affect the contractors' decision on which method to use. Depending upon the location of the construction site, mail order may be the only way to get the special coils for the automatic machines. On the other hand, the traditional black wire commonly used in the pliers and pigtail methods is available in most hardware stores. Moreover, powered tying machines require periodic maintenance that may cost up to $200 annually. It is clear that the cost of using powered tying machines is more expensive than the cost of using the traditional methods, and thus powered tying machines may not be as readily accepted. However, the increased productivity of workers, and improved comfort and safety when using powered tying tools may offset the high operating costs of these tools.

Job De-Skilling

Although the rebar tying task may seem basic and simple, it requires a certain type and level of skill. It is important to twist the wire just enough to achieve the proper wire tension. Excess twisting may break the wire, and under twisting may result in a loose tie that may not hold the rebar rods in place. Rebar workers take pride in their ability to tie different types of ties properly and in how fast they are able to do it. On the other hand, powered machines requires less skills to operate. To operate a powered tying machine, the worker places the jaws of the machine around the two rods to be tied and presses a trigger. It is expected that some workers would reject powered tying machines because it would de-skill their job. However, it is unlikely that the need for skilled rebar workers would be eliminated by the use of powered tools. There are other skills that are important for the job such as reading blueprints, recognizing different sizes of rebar, cutting rods to proper lengths, and dealing with scaffolds, cranes, fall protection and other general techniques used in construction.

Rehabilitation Tool

At certain times, rebar workers experience discomfort that may affect their productivity. One of the interviewed workers reported that he was seeing a doctor for pain in his hands. He was told that he has tenosynovitis, and was prescribed a treatment of anti-inflammatory medication and rest. The worker also said that it is not possible for him to stop working because "if he does not work he would not get paid," and instead of stopping he opted to do less tying and more of the other tasks.

Powered tying tools may present a solution for an injured worker and the employer. It may enable the worker to continue working productively without the need for wrist twisting, which would aggravate the injury.

Alternatives to Rebar Tying

Using prefabricated rebar mesh, and fiber reinforced concrete may reduce the need for rebar tying. Prefabricated rebar meshes consist of rebar rods that are welded together, and are only available for small sizes of rebar. Prefabricated rebar meshes are usually used in four inch concrete slabs, such as sidewalks and driveways.

Fiber reinforced concrete is a method for concrete construction that does not use any rebar. Fiber reinforced concrete was first introduced in the 1940s, and since then has been significantly improved. Currently, fiber reinforced concrete is used successfully in four inch slabs with no need for rebar. It is not likely, however, that fiber reinforced concrete will eliminate the need for rebar in large structures.

Conclusions

Based on our observational evaluation of the rebar tying task, physical risk factors were identified. These factors include repetitive work, bending, working with a deviated wrist, pulling forcefully, doing a hammering-like movement, and twisting at the wrist. Workers may feel discomfort or pain in the hand, wrist, elbow, shoulder, or lower back areas.

Our evaluation also indicated that powered tying tools may reduce workers' exposure to physical risk factors such as bending, working with deviated wrist, and twisting at the wrist, and thus, have the potential to reduce negative health consequences of the rebar tying task. However, similar to other powered tools, powered tying tools may have unique physical risk factors. These factors may include excessive moments on the joints of the body caused by the weight of the tool, kick-back forces on the hand at the end of the cycle, and vibration. In general, the weight of a hand tool should not exceed five pounds.[15] Also, newer and well-maintained tools would have lower kickback forces and less vibration than older, worn out tools.

Powered tools only tie rebar up to 19 mm in diameter, which covers only part of the rebar sizes used in construction. It is expected that future models of power tying machines would be designed to handle all rebar sizes, and would be able to tie rebar to spacers, as well as tie rebar to rebar.

The rebar chairs and the rebar stapler methods can only be used on horizontal applications. These methods may decrease workers' exposure to physical risk factors, but because of their limited usability, they would only solve part of the problem.

Research is needed to evaluate the impact of each rebar tying method on the productivity and well-being of workers. Additional research required includes field studies that would comprise measures of workers' health (such as body part discomfort ratings), and measures of workers' performance while using the different rebar tying methods. Also, studies to analyze and identify movements and forces involved in the rebar tying task for each method are needed. The outcome of such research studies would provide the foundation for the design and development of a rebar tying tool that would enhance workers' productivity and protect their health. Rebar tying powered tools have the potential to reduce injuries, but improvements are needed to reduce the total weight of the tool, to widen the range of sizes of rebar that the tool is able to tie, and to be able to make different types of ties.

REFERENCES

1. National Institute for Occupational Safety and Health (NIOSH), NIOSH Research Project/August 1997, NIOSH, 4676 Columbia Parkway, Cincinnati, OH (1997).
2. Schneider, S.: Implement Ergonomic Intervention in Construction. App Occup Env Hyg 10(10):822–824 (October 1995).
3. Schneider, S.; Susi, P.: Ergonomics and Construction: A Review of Potential Hazards in New Construction. Amer Ind Hyg Assn J 55(7):635–649 (1994).
4. Wickstrom, G.; Hanninen, K.; Lehtinen, M.; Riihimaki, H.: Previous Back Symptoms in Concrete Reinforcement Workers. Scan J Work Environ Hlth 1(suppl):20–28 (1978).
5. Saari, J.; Wickstrom, G.: Load on Back in Concrete Reinforcement Work, Scan J Work Environ Hlth 4(suppl. 1):13–19 (1978).

6. Bureau of Labor Statistics (BLS): National Occupational Employment and Wage Estimates, 87314 Reinforcing Metal Workers, http://stat.bls.gov/oes/national/oes87314.htm (1997).
7. Bureau of Labor Statistics (BLS): Table R30: Incidence rates for nonfatal occupational injuries and illnesses, http://www.bls.gov (1997).
8. Bureau of Labor Statistics (BLS): Table R27: Number of nonfatal occupational injuries and illnesses, http://www.bls.gov (1997).
9. Bureau of Labor Statistics (BLS): Table R26: Number of nonfatal occupational injuries and illnesses, http://www.bls.gov (1997).
10. Bureau of Labor Statistics (BLS): Table R55: Number of nonfatal occupational injuries and illnesses, http://www.bls.gov (1997).
11. Bureau of Labor Statistics (BLS): Table R56: Number of nonfatal occupational injuries and illnesses, http://www.bls.gov (1997).
12. Bureau of Labor Statistics (BLS): Table R57: Number of nonfatal occupational injuries and illnesses, http://www.bls.gov (1997).
13. Bureau of Labor Statistics (BLS): Table R58: Number of nonfatal occupational injuries and illnesses, http://www.bls.gov (1997).
14. University of Cincinnati, Department of MINE. Design of a Rebar Tying Tool for CDC/NIOSH, unpublished.
15. Dababneh, A.; Waters, T.: The Ergonomic Use of Hand Tools: Guidelines for the Practitioner. App Occup Env Hyg 14:208–215 (1999).
16. Southhold International, Product literature/U-TIER, South Bend, IN.
17. New Century NORTHWEST, Product literature/Rebar Support Chairs, Eugene, OR.
18. GLIM BETONGPRODUKTER AB, Product literature/The Glim Scan System, Norrkoping, Sweden.
19. Max Co. Ltd., Product literature/ REBAR-TIER, New York Liaison Office, Garden City, NY.
20. U-Binder, Product literature/U-BINDER, www.informat.or.jp/kanazak07/go.htm.
21. Takahashi, S.; Kaneko; Youzou, S.; Saito; Tsutomu: U.S. Patent No. 5682927, U.S. Patent and Trademark Office, Washington, DC (1997).

EDITORIAL NOTE: Dr. Awwad J. Dababneh is a National Research Council Fellow at the National Institute for Occupational Safety and Health (NIOSH) in Cincinnati, OH. He has a Ph.D. in Industrial Engineering and is a certified professional ergonomist. Dr. Debabneh conducts ergonomic research studies at NIOSH focusing on hand tool design, ergonomic interventions, and safety and health issues in the construction industry. He has published numerous papers in safety and health journals.

Dr. Thomas R. Waters is the Chief of the Human Factors and Ergonomics Research Section of the Division of Applied Research and Technology at the National Institute for Occupational Safety and Health (NIOSH) in Cincinnati, OH. He is a certified professional ergonomist and holds a Ph.D. in Biomechanics from the University of Cincinnati and is an adjunct professor in the Mechanical Engineering Department at the University of Cincinnati and at The Ohio State University. Dr. Waters conducts ergonomic research studies focusing on manual material handling, prevention of low back disorders, and exposure assessment methods. Dr. Waters is well known for his work on the Revised NIOSH Lifting Equation.

For additional information, contact Dr. Thomas Waters at (513) 533-8147 or e-mail at trw1@cdc.gov.