JHT READ FOR CREDIT ARTICLE #243.

Hand Grip Function Assessed by the Box and Block Test Is Affected by Object Surfaces

Na Jin Seo, PhD
Leah R. Enders, MS
Department of Industrial and Manufacturing Engineering, University of Wisconsin-Milwaukee, 3200 North Cramer Street, Milwaukee, Wisconsin

ABSTRACT:
Study Design: N/A.
Background: One of the hand function assessment tools is the Box and Block Test (BBT).
Purpose: To examine if the BBT score is affected by grip surfaces.
Methods: Thirteen adults performed the BBT with wooden, rubber-covered, and paper-covered blocks. The BBT scores and time for seven movements (finger closing, contact to lift-off, transport before barrier, transport after barrier, release, return, and reach) were compared across the three block types.
Results: The mean BBT score was 8% higher for the rubber blocks than the paper and wooden blocks ($p < 0.01$) due to the reduced time for contact to lift-off (when the finger touches a block until the block is lifted).
Conclusions: Hand function assessments should be controlled for object surfaces. Therapists may vary grip difficulties by changing object surfaces. Redesigning daily objects with high-friction surfaces may increase grip function.
Level of Evidence: N/A.
J HAND THER. 2012;25:397–405.

Successful grasp, transfer, and release of objects with the hand are important movements for completing many everyday tasks. Transporting objects from one place to another is a frequently performed movement at workplaces. For their functional prevalence and significance, grasp and release movements have been incorporated into many clinical hand function assessments, such as the Box and Block Test (BBT).

The BBT is a common test used to assess people's hand grip function.[1,2] In the BBT, people are instructed to grasp a block from one side of a box, transport the block over a middle barrier, release the block to the other side of the box, and repeat the procedure as fast as possible (Figure 1). The number of blocks moved within 60 seconds determines the BBT score. The BBT has been used to determine deficiency in manual dexterity in patient populations such as cerebral palsy.[3] Its reliability and validity have been well documented in literature.[4] The normative data for the BBT score have been established for different ages,[1,4] gender,[1] and hand dominance.[1] The BBT can also be used to simulate grasp and transport movements within workplace settings.

The speed of a person's upper limb movement and hand function score, as assessed by the BBT, can depend on the characteristics of the objects to be grasped or transported and the task-specific requirements. For example, the hand's movement time for transporting objects is reported to be affected by the weight of the object being transported, movement direction, and traveling distance.[5–7] Increased demands for accuracy, such as reduced tolerance for error in the final location of an object, can slow down hand movements.[8–10]

The slipperiness of an object's surface also can affect movement time. For example, the hand movement time for reaching and grasping an object (before lifting the object) has been shown to be affected by the surface friction condition of the object.[11–13] Unfortunately, these studies did not look at the effect of object surfaces on the entire grasp-and-release cycle time (including hand movement time during

A portion of the findings in this study was presented at the American Society of Biomechanics conference in Providence, RI, August 2010, and the Society for Neuroscience conference at San Diego, CA, November 2010. The presentations were in poster format.

Correspondence and reprint requests to Na Jin Seo, PhD, University of Wisconsin-Milwaukee, 3200 North Cramer Street, Milwaukee, Wisconsin, 53211; e-mail: <seon@uwm.edu>.

doi:10.1016/j.jht.2012.04.004

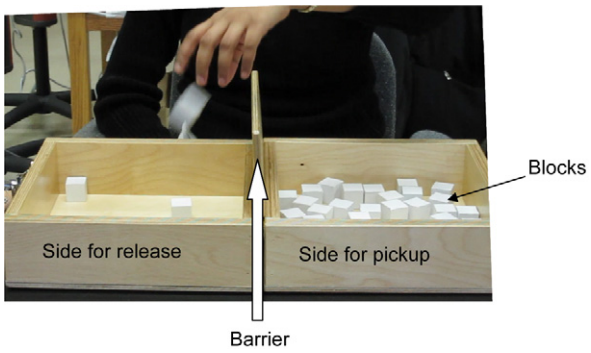

FIGURE 1. *For the Box and Block Test, subjects picked up one block from one side (right) and moved it to the other side, passing the hand over the barrier and releasing the block on the opposite side (left).*

object transport, release, or repeated cycles of grip and release of objects). Therefore, it is unclear how these findings will translate to clinical hand function scores that assess hand grip and release function as a whole. One study investigated the cycle time for repeated grip and release movements for different coefficients of friction (COFs) of object surfaces.[5] Yet, they found no significant effect of the COF conditions of grasped objects on the cycle time. In that study, however, subjects were instructed to move at a slow self-paced speed, unlike many clinical hand function tests, including the BBT, that instruct people to move as fast as possible. Currently, there is an incomplete picture of how COF affects clinical hand function score and movement time for different components of grasp and release tasks.

In summary, it is unclear if the surface friction conditions of objects to be grasped and transported can affect clinical hand function scores. It is also unknown how the use of different surface objects affects movement time during various stages of the reach, grasp, transport, and release movement cycle. Therefore, the objective of the present study was to determine the effect of block surfaces with different COFs on the BBT score and the time spent for different stages of movement during the BBT. It was hypothesized that an increase in the COF of blocks increases the BBT score. This hypothesis was formulated based on the studies identified above that reported reduced reaching and grasping time with increased object surface COF.[11–13] In addition to testing the hypothesis, the effect of block COF on the time spent for each movement stage was examined.

METHODS

Subjects

Thirteen healthy young subjects (five males and eight females) participated in this study. Their ages ranged from 20 to 30 years (mean = 24, standard deviation = 3). They had no history of orthopedic problems in the upper limb. Twelve subjects were right handed, and one subject was left handed. All subjects signed a consent form and followed a protocol approved by the institutional review board.

Procedure

To determine the effect of block surfaces on the BBT score, subjects were instructed to perform the BBT (Patterson Medical, Inc., Bolingbrook, IL) for three different block types: standard painted wooden blocks (COF of 0.5 with skin[14]), blocks covered in paper (COF of 0.3 with skin[15]), and blocks covered in a smooth thin sheet of rubber (COF of 0.9 with skin[16]). All blocks weighed within 11.5 ± 1 g and had all sides within 25 ± 1 mm. Subjects were instructed to move as many blocks as possible from one side of a box to the other side (the box was divided in half with a barrier) (Figure 1) within 60 seconds. The total number of blocks moved during this time determined the BBT score. Subjects performed the BBT twice per block type (a total of six trials) using the nondominant hand. The nondominant hand was used because it moves more slowly for dexterous movements compared with the dominant hand[1,17–19] and thus may merit improvement. The block types were presented to the subjects in a random order.

On arrival to the laboratory, subjects were asked to wash and dry their hands to remove any potential contaminants.[16] Before testing, subjects were allowed to practice the BBT to become familiar with the test. All BBTs were performed with the subjects seated at a table. The height of the table was approximately at the level of the subjects' elbow when seated. Subjects were instructed to move one block at a time and pass their hand completely over the barrier, according to the literature.[1] No specific instruction on how to grip the block was provided. During the tests, the subjects primarily used a pinch grip with the thumb and the index finger, allowing the other fingers to assist as needed. Rest breaks were given between trials to minimize muscle fatigue. All BBT trials were recorded using a video camera (Canon PowerShot SD780 IS; Canon U.S.A., Inc., Lake Success, NY) at 30 Hz for motion time analysis.

Motion Time Analysis

To determine the effect of block surfaces on the amount of time needed to complete specific movements during the BBT, all videotaped BBT trials were analyzed for motion time analysis. Movements associated with a single block transfer were broken down to seven stages (finger closing, contact to lift-off, transport before barrier, transport after barrier, release, return, and reach) (Figure 2), which are further described below. The amount of time that subjects

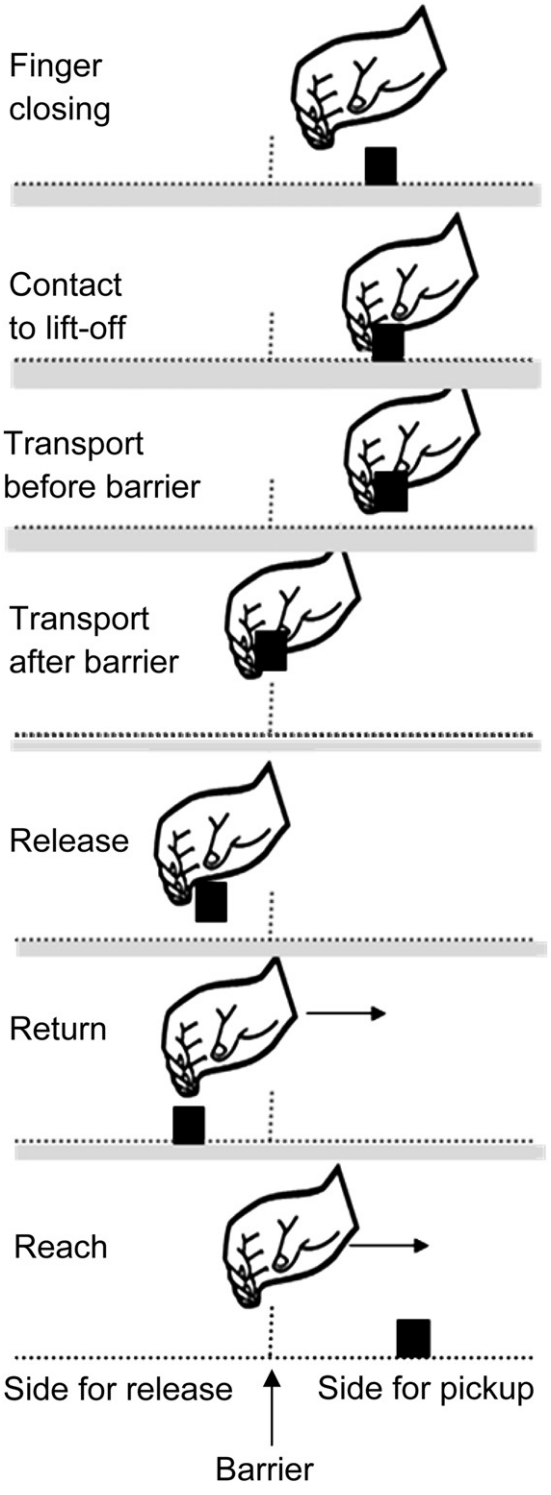

FIGURE 2. *Seven stages associated with the Box and Block Test were defined as finger closing, contact to lift-off, transport before barrier, transport after barrier, release, return, and reach. The hand position at the beginning of each stage is shown.*

took to complete each stage (referred to as ''stage time'') was determined by counting the number of video frames that were associated with each stage and then converting it to milliseconds.

The seven stages are defined as follows. 1) The finger closing stage begins one frame before the first frame in which the index finger's metacarpophalangeal joint starts flexing while the hand is moving toward a block to be picked up and ends one frame before the finger touches the block; 2) The contact to lift-off stage begins with the frame in which the finger makes contact with the block and ends one frame before the block is lifted off the bottom of the box; 3) The transport before barrier stage begins with the frame in which the block leaves the bottom of the box and ends one frame before the block is closest to the midline (directly over barrier) between the two sides of the box (regardless of whether the block passes the barrier or not). The end of this stage (one frame before the block is closest to the midline) always occurs before the block passes the barrier; 4) The transport after barrier stage begins with the frame in which the block is closest to being directly over the barrier and ends one frame before the block is released; 5) The release stage begins with the frame in which the block leaves contact with all fingers and is in free fall and ends one frame before the hand starts moving back; 6) The return stage begins with the frame in which the hand begins progressing back to the other side of the box to pick another block and ends one frame before the middle of the hand is closest to the barrier; and 7) The reach stage begins with the frame in which the middle of the hand is closest to the barrier, ending two frames before the fingers begin closing for the next block. Each frame is counted only once for a single stage (no overlap).

The very first and last stages of each BBT trial were not included in the motion time analysis to reduce transitional effects from movement initiation or termination. The first stage of a BBT trial was reaching. The last stage was one of the seven stages, depending on what the subject was doing when the 60 seconds ended.

Statistical Analysis

To determine the effect of block surface types on the BBT score and stage times, two repeated measures analyses of variance (ANOVAs) were run. The first ANOVA determined if the within-subject variable of block surface type (painted wood, paper, and rubber; fixed effect) significantly affected the dependent variable of the BBT score. The BBT score data met the assumption of normality using the Kolmogorov-Smirnov test ($p > 0.05$). To determine if the BBT score for one block type was significantly different from that for another block type, a Tukey pairwise comparison was used for individual comparisons among the BBT scores for the three block surface types.

The second ANOVA determined if stage time significantly varied for the block surface type, stage, and their interaction. Both block surface type and stage were within-subject variables (fixed effects). A

Tukey pairwise comparison was used to compare stage time differences among the three block surface types and stages. The stage times were averaged across all blocks moved within a BBT trial. The stage time data did not meet the assumption of normality using the Kolmogorov–Smirnov test ($p < 0.05$). Therefore, the stage time data were transformed to stage time raised to the power of 1/1.33 to meet the assumption of normality ($p > 0.05$). The same ANOVA results were found for both stage time itself and stage time raised to the power of 1/1.33, probably because the *F* statistic is quite robust against the violation of normality.[20] The p-values reported in this study represent the results from both ANOVAs (for stage time and for stage time raised to the power of 1/1.33). The p-value of 0.05 was considered significant for all statistical tests.

RESULTS

BBT Score

The BBT score varied significantly depending on the block surface types ($p < 0.01$). On average, the number of rubber blocks that subjects could move was 8% greater than the number of paper and wooden blocks (Figure 3; $p < 0.01$). The BBT score was not significantly different between the paper and wooden blocks ($p = 0.33$).

Stage Time

The time associated with each movement stage (stage time) varied significantly depending on the block surface types, stages, and their interactions (Figure 4; $p < 0.05$ for all). The mean stage time for the rubber blocks (115 ms) was 6% less than that for the paper and wooden blocks (122 ms for both paper and wooden blocks) when averaged for all stages ($p < 0.05$ from pairwise comparison). The stage time was not significantly different between the paper and wooden blocks ($p > 0.05$). Pairwise comparisons among all stages showed that the transport before barrier and reach stages took the longest time (177 ms), followed by contact to lift-off (145 ms), transport after barrier and return (109 ms), finger closing (94 ms), and release (30 ms) stages, with statistical significance ($p < 0.01$).

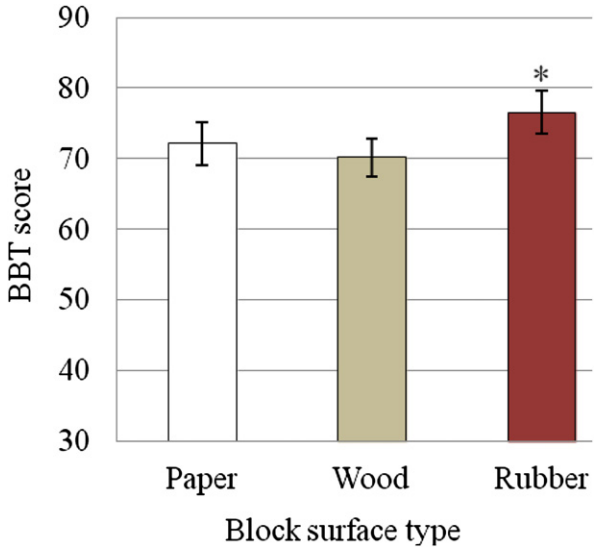

FIGURE 3. *The mean ± standard error Box and Block Test (BBT) scores (the number of blocks moved in 60 sec) for the three block surface types (pooled for subjects and repetitions). The BBT score was 8% greater for the rubber blocks than for the paper and wooden blocks ($p < 0.01$).*

Pairwise comparisons within each stage showed that the time spent for the contact to lift-off stage was significantly less for the rubber blocks than for the other blocks ($p < 0.01$). The mean time spent for the contact to lift-off decreased 26% and 20% for the rubber blocks compared with the paper and wooden blocks, respectively (Figure 4). The contact to lift-off stage time was not significantly different between the wooden and paper blocks ($p > 0.05$). The effect of block surface type on stage time was not found to be significant for other stages ($p > 0.05$).

DISCUSSION

Effect of Block Surface on BBT Score and Contact to Lift-off Stage Time

When gripping high-friction rubber blocks, subjects were able to move an average of 8% more blocks compared with the paper and wooden blocks (Figure 3). Specifically, the length of time subjects spent during the contact to lift-off stage decreased by 23% when using the rubber blocks compared with the other blocks (Figure 4). This finding is consistent with a previous study that reported that the contact to lift-off time was 29% less for subjects gripping dowels with nonslippery surfaces than for those gripping dowels with slippery surfaces.[12] The difference between the wooden and paper-finished blocks was not significant for both the BBT score and stage time, possibly because the paper and wooden surfaces have a relatively similar COF (COF difference within 0.2), whereas the rubber surface had a relatively high COF (with a difference of 0.4 and 0.6 for the wooden and paper surfaces, respectively).

Subjects may have been able to decrease their contact to lift-off time and improve their BBT score for the rubber surface for two reasons. First, subjects may have achieved a minimally required grip force to lift the high-friction rubber blocks sooner compared with the other blocks that had lower COFs. It is well known that an increase in COF between an object surface and finger skin decreases the minimum required grip force needed for a person to lift the block

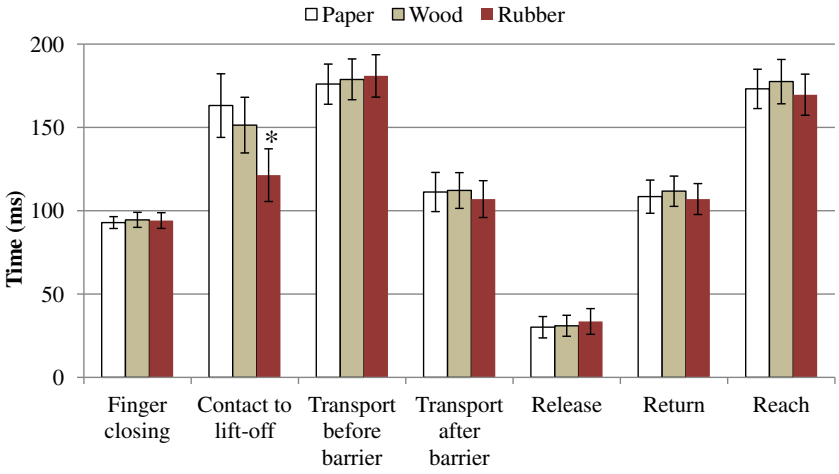

FIGURE 4. *The mean ± standard error time, in milliseconds, spent for each of the seven stages of a block transfer during the Box and Block Test is shown (pooled for subjects, all blocks moved in a single BBT, and repetitions) for three different block surface types (paper, wood, and rubber). The contact to lift-off time for the rubber blocks was 26% and 20% less than that for the paper and wooden blocks, respectively ($p < 0.01$).*

off a table.[21,22] It takes more time to reach a high-force level than a low-force level.[23,24] Therefore, the decrease in the minimum required grip force for the high-friction rubber blocks may have reduced the amount of time needed for the subjects to attain the grip force necessary to lift the blocks compared with the low-friction blocks.

Second, the high-friction rubber blocks may have lowered the level of precision required for directing digit force on the blocks, resulting in faster contact to lift-off movement. To grip an object without slippage, the digit force has to be applied to the object surface in a direction that is within an allowed angle range defined by the cone of friction.[25] This angle range is greater for high-friction surfaces, which requires less precision in digit force direction compared with low-friction surfaces (Figure 5).[26,27] With this reduced level of precision, subjects may have been able to pick up blocks with a high-friction rubber surface faster than those with relatively low-friction paper and wooden surfaces.

Insignificant Block Surface Effect for Other Stages

Other than contact to lift-off, the amount of time spent for the stages (i.e., finger closing, transport before barrier, transport after barrier, release, return, and reach) did not significantly vary by block surface type. This finding is consistent with a previous study that found that the contact to lift-off time but not the reach/finger closing time is affected by object surface types.[12] Other studies have suggested that precontact movement time (e.g., reaching until contacting an object) can change depending on the slipperiness of objects, when subjects grip objects with different surfaces for each consecutive grip.[11,13] However, when subjects gripped a batch of objects with one surface

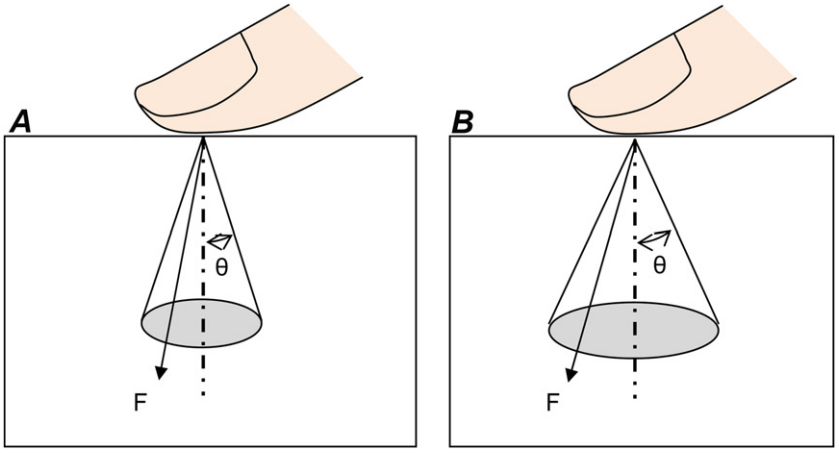

FIGURE 5. *The cone of friction defines the angle range (θ = arctangent of COF) in which the digit force, F, can be applied to an object surface without slippage. This allowed angle range increases as the surface–finger COF changes from low (**A**) to high (**B**). COF = coefficient of friction.*

type repeatedly and then gripped another batch of objects with a different surface type repeatedly (in a block design, such as in the present study), the surface effect on movement preparation time was insignificant,[13] consistent with the present study's finding. Planning for grip formation takes place before touching an object (e.g., during reaching).[11] It is possible that when objects with different surfaces are gripped in a random order, the amount of time needed to plan grip formation may vary depending on each object's surface, whereas in the blocked condition, sensorimotor memories based on previous grips can be used, thereby mitigating the effect of the surface type on precontact movement time. In daily living, in which objects with various surfaces are gripped in a random fashion, the movement preparation time (i.e., reach and finger closing stage time) could increase for slippery objects, as suggested by Fikes et al.[13] and Fleming et al.[11]

The amount of time spent in the release stage did not vary significantly for block surfaces. To release a block, a person must decrease the grip force below the slip force (i.e., the minimally required grip force to hold the block against gravity). The time spent for releasing may be related to the amount of force reduction needed to reach the slip force, as grip force control has been shown to follow Fitts' law (i.e., a larger change in grip force takes longer to achieve).[23,24] However, people may use a similar safety margin (i.e., additional grip force than slip force[21,22]) during grip regardless of the object surface for a given object weight.[28] Thus, the amount of time to reduce the grip force below the slip force may have been similar for all block surface types.

Functional and Clinical Implications

The findings in the present study have significant implications for rehabilitation and therapies. As reported in the present study, the 8% increase in the BBT score for blocks with the rubber surface is considered sizable compared with the 3% increase in the BBT score for subjects using the dominant versus nondominant hand and with the 24% reduction in the BBT score with aging (70 yr or older vs. 20–29 yr).[1] This effect of object surfaces on movement time complements force-based observations described in the previous studies.[29,30] However, the implications for people with hand impairments discussed in this section should be taken with caution because the data in the present study were obtained only from healthy people and not from patients with hand impairments.

First, for therapies involving grasping, therapists may decrease or increase difficulties by using objects with high-friction or low-friction surfaces to encourage or challenge patients, respectively. The results of the present study support this strategy, which therapists may already be using with their patients. These results explain the effect of object surface friction on hand grip function.

Second, when clinical hand function assessment tools are used to evaluate therapy outcomes, object surface types should remain the same across different evaluation sessions. A patient's hand function score may be directly compared with the normative data only if the data were obtained with the same object surface type. Controlling the surface type is especially important because the contact to lift-off stage time often changes with improved function in people with disability.[31]

Third, in occupational settings where the repeated and rapid grip of objects is required, high-friction conditions between the hand and objects may shorten grip movement time. At the same time, wetness or soapiness between the hand and objects that are associated with low friction[32] may prolong grip movement time. The use of gloves that affect the COFs at the hand–object interface[30,33] may also affect people's hand grip time. The present study also suggests that people with abnormally dry skin may have low hand function scores, not because of their motor coordination but because of the low skin friction.[34] This concept of object surface affecting movement time may be applied to work assignments for people who return to work after a hand injury, in which a light-duty task is assigned at first and more difficult tasks are introduced progressively.

Fourth, in home settings, the use of high-friction surfaces for everyday objects such as eating, writing, and cooking may improve the time efficiency for obtaining objects. Such ergonomic interventions are expected to be particularly beneficial for people with sensorimotor impairments. For instance, patients with stroke are reported to have difficulty in directing finger forces.[35] The use of high-friction objects to increase the size of the cone of friction (Figure 5) may improve BBT scores for these patient populations. Such rehabilitative benefits warrant further evaluation for specific patient populations.

Limitations

Although the present study demonstrates that clinical hand function scores in young healthy people can vary depending on the surfaces of the grasped object, the surface effect for patient populations with upper extremity injuries or impairments, such as median nerve injury, was not examined and has yet to be demonstrated. The object surface effect on hand function may vary depending on the pathology and handedness, which warrants further investigation. The present study investigated the object surface effect only on one hand function test (BBT). Although it is plausible that other functional assessments involving hand grip may be influenced by the surface

of an object, this study does not quantify the impact of surface change on other hand function tests. The present study investigated only light objects (weighing 11.5 g). The extent to which the findings of the present study are applicable to heavy objects is unknown. Increasing object weight increases the difference in the minimum required grip force and the safety margin.[28] Therefore, it is possible that the surface type effect could be more pronounced and observed in more movement stages for heavy objects than light objects.

CONCLUSIONS

The present study demonstrated that objects with rubber surfaces improved people's hand function assessed by the BBT, possibly by increasing the COF between the fingers and objects. This improvement appears to be due to the decreased time spent in the contact to lift-off stage for the rubber blocks compared with the paper and wooden blocks. This finding suggests that object surface types used in clinical hand function assessments should be controlled or remain constant for valid comparison. In addition, therapists may vary difficulties by using objects with high-friction or low-friction surfaces to encourage or challenge patients, respectively. Lastly, redesigning daily objects by changing grip surfaces may benefit people with sensorimotor impairment by improving their hand grip function and speed.

Acknowledgments

This study was partially funded by the University of Wisconsin-Milwaukee College of Engineering & Applied Science and by the University of Wisconsin-Milwaukee Research Growth Initiative. The authors thank Rex Allen, Jeremy Hildebrand, Daniel Cary, and Jay Kapellusch for their assistance regarding the motion time analysis.

REFERENCES

1. Mathiowetz V, Volland G, Kashman N, Weber K. Adult norms for the Box and Block Test of manual dexterity. Am J Occup Ther. 1985;39:386–91.
2. Trombly C. Occupational Therapy for Physical Dysfunction. Baltimore, MD: Williams and Wilkins, 1983.
3. Cromwell F. Occupational Therapists Manual for Basic Skill Assessment: Primary Prevocational Evaluation. Altadena, CA: Fair Oaks Printing, 1976.
4. Desrosiers J, Bravo G, Hebert R, Dutil E, Mercier L. Validation of the Box and Block Test as a measure of dexterity of elderly people: reliability, validity, and norms studies. Arch Phys Med Rehabil. 1994;75:751–5.
5. Frederick LJ, Armstrong TJ. Effect of friction and load on pinch force in a hand transfer task. Ergonomics. 1995;38:2447–54.
6. Bailey GB, Presgrave R. Basic Motion Time Study. New York, NY: McGraw-Hill, 1958.
7. Corrigan RE, Brogden WJ. The trigonometric relationship to precision and angle of linear pursuit-movements. Am J Psychol. 1949;62:90–8.
8. Fitts PM. The information capacity of the human motor system in controlling the amplitude of movement. J Exp Psychol. 1954; 47:381–91.
9. Marteniuk RG, MacKenzie CL, Jeannerod M, Athenes S, Dugas C. Constraints on human arm movement trajectories. Can J Psychol. 1987;41:365–78.
10. Klatzky RL, Fikes TG, Pellegrino JW. Planning for hand shape and arm transport when reaching for objects. Acta Psychol (Amst). 1995;88:209–32.
11. Fleming J, Klatzky RL, Behrmann M. Time course of planning for object and action parameters in visually guided manipulation. Vis cognit. 2002;9:502–27.
12. Weir PL, MacKenzie CL, Marteniuk RG, Cargoe SL. Is object texture a constraint on human prehension?: kinematic evidence. J Mot Behav. 1991;23:205–10.
13. Fikes TG, Klatzky RL, Lederman SJ. Effects of object texture on precontact movement time in human prehension. J Mot Behav. 1994;26:325–32.
14. Bullinger HJ, Kern P, Solf JJ. Reibung Zwischen hand und griff, Forchungs bericht Nr 213. (Friction between Hand and Handle, Research Report No. 213). Dortmund, Germany: Bundesanstalt fur Arbeitsschutz und Unfall-forchung, 1979.
15. Buchholz B, Frederick LJ, Armstrong TJ. An investigation of human palmar skin friction and the effects of materials, pinch force and moisture. Ergonomics. 1988;31:317–25.
16. Seo NJ, Armstrong TJ. Friction coefficients in a longitudinal direction between the finger pad and selected materials for different normal forces and curvatures. Ergonomics. 2009;52: 609–16.
17. Annett M. Five tests of hand skill. Cortex. 1992;28:583–600.
18. Flowers K. Handedness and controlled movement. Br J Psychol. 1975;66:39–52.
19. Ozcan A, Tulum Z, Pinar L, Baskurt F. Comparison of pressure pain threshold, grip strength, dexterity and touch pressure of dominant and non-dominant hands within and between right-and left-handed subjects. J Korean Med Sci. 2004;19: 874–8.
20. Ito PK. 7 Robustness of ANOVA and MANOVA Test Procedures. In: Krishnaiah PR (ed). Handbook of Statistics. Vol 1. Oxford, UK: Elsevier, 1980. pp. 199–236.
21. Westling G, Johansson RS. Factors influencing the force control during precision grip. Exp Brain Res. 1984;53:277–84.
22. Johansson RS, Westling G. Roles of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery objects. Exp Brain Res. 1984;56:550–64.
23. Kim NH, Escaldi S, Shain A, Wininger M, Craelius W. Improving grip control using a dynamic speed-accuracy tradeoff protocol. RESNA Annual Conference. Arlington VA, 2008.
24. Kim NH, Wininger M, Craelius W. Training grip control with a Fitts' paradigm: a pilot study in chronic stroke. J Hand Ther. 2010;23:63–71, quiz 72.
25. MacKenzie CL, Iberall T. The Grasping Hand. Amsterdam: Elsevier, 1994.
26. Enders LR, Seo NJ. Phalanx force magnitude and trajectory deviation increased during power grip with an increased coefficient of friction at the hand-object interface. J Biomech. 2011; 44:1447–53.
27. Seo NJ, Shim JK, Engel AK, Enders LR. Grip surface affects maximum pinch force. Hum Factors. 2011;53:740–8.
28. Seo NJ. Dependence of safety margins in grip force on isometric push force levels in lateral pinch. Ergonomics. 2009;52: 840–7.
29. Seo NJ, Armstrong TJ, Chaffin DB, Ashton-Miller JA. The effect of handle friction and inward or outward torque on maximum axial push force. Hum Factors. 2008;50:227–36.
30. Seo NJ, Armstrong TJ, Young JG. Effects of handle orientation, gloves, handle friction, and elbow posture on maximum horizontal pull and push forces. Ergonomics. 2010;53:92–101.
31. Eliasson AC, Forssberg H, Hung YC, Gordon AM. Development of hand function and precision grip control in individuals with cerebral palsy: a 13-year follow up study. Pediatrics. 2006;118:1226–36.

32. O'Meara DM, Smith RM. Static friction properties between human palmar skin and five grabrail materials. Ergonomics. 2001;44:973–88.
33. Laroche C, Barr A, Dong H, Rempel D. Effect of dental tool surface texture and material on static friction with a wet gloved fingertip. J Biomech. 2007;40:697–701.
34. Loden M, Olsson H, Axell T, Linde YW. Friction, capacitance and transepidermal water loss (TEWL) in dry atopic and normal skin. Br J Dermatol. 1992;126:137–41.
35. Seo NJ, Rymer WZ, Kamper DG. Altered digit force direction during pinch grip following stroke. Exp Brain Res. 2010;202: 891–901.

JHT Read for Credit
Quiz: Article #243

Record your answers on the Return Answer Form found on the tear-out coupon at the back of this issue or to complete online and use a credit card, go to *JHTReadforCredit.com*. There is only one best answer for each question.

#1. According to the text the reliability of the BBT
   a. has been shown to be suspect
   b. was tested and demonstrated in this study
   c. has previously been reported in the literature
   d. was not addressed in this article

#2. The study population consisted of
   a. a mix of healthy subjects and patients with hand injuries
   b. a large group of healthy subjects
   c. a small group of healthy subjects
   d. all subjects with hand injuries

#3. The group with the fastest ''pick up times'' was the
   a. rubber surfaced blocks
   b. smooth wooden blocks
   c. paper surfaced blocks
   d. cement blocks

#4. The subjects picked up the blocks with
   a. their dominant hand
   b. their non-dominant hand
   c. whichever hand they wanted
   d. their dominant hand for the first ten blocks and their non-dominant hand for the remainder

#5. The nature of the BBT allows it to be easily applied to a broad spectrum of hand functions
   a. true
   b. false

When submitting to the HTCC for re-certification, please batch your JHT RFC certificates in groups of 3 or more to get full credit.