# User Capabilities Versus Device Task Demands in a Tape Dispenser Product for Persons with Limited Dexterity

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## 1 Introduction

The creation of a product that will be effective in aiding users who have physical limitations presents a designer with many difficult challenges. Users of assistive devices represent a continuum of abilities (Cook et al. 2008), from those with slight to moderate disabilities who may have more general needs to those with more severe disabilities who may have very unique and specific needs. An assistive device may therefore function well for one group of users but poorly for another. This continuum can be a challenge for a company as it often results in small, niche markets for such devices (Cowan and Turner-Smith 1999). It is also a challenge for designers because they draw upon their own experiences and knowledge while investigating potential solutions to a design problem (Norman, 1988). Designers are trained to imagine themselves in the shoes of the user (Nieusma 2004). But since most do not themselves suffer from physical limitations, it is much more difficult to imagine themselves in the shoes of a user who has lost some basic ability to interact with the world that the designer can take for granted. Even if the designer has a physical limitation, unless it is of the same type and severity as the target user's, it may not provide much relevant personal experience to draw upon. Tools or other guidance that can aid designers in eliminating interactions with products that might pose a barrier to use can be important in improving a product's effectiveness as well as an end user's level of satisfaction. This paper will investigate the link between devices designed to aid in the task of taping closed a box and common ergonomic measurements of dexterity.

Upper extremity (UE) function plays an important role in one's ability to perform activities of daily living (ADL) (Desrosiers et al. 1999). UE function may become reduced for a variety of reasons such as age, injury or disease. Accurate

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measurement of UE function is important in evaluating the effectiveness of surgical procedures or rehabilitation strategies. UE function includes motor coordination, manual dexterity, muscle strength, and sensibility (Özcan et al. 2004).

Manual dexterity has been defined as the ability to combine precision and speed with coordinated movements of the arm, hand, and fingers (Özcan et al. 2004). A tool commonly used for testing manual dexterity is the nine hole peg test (NHPT) which is a timed test of finger dexterity and fine motor coordination. It is commonly used by occupational therapists as a quick assessment of dexterity function (Grice et al. 2003; Wang et al. 2011).

Grip and pinch strength are considered to provide an objective measurement of UE integrity (Incel et al. 2002). Grip strength (also known as power grip) is typically measured with a dynamometer where the base rests against the heel of the palm and the handle on the middle of the four fingers. The user then squeezes with maximum effort which is measured by the device. Pinch strength can be measured in a number of ways. One is a "tip pinch" in which the user pinches using the tip of the thumb to the tip of the index finger. Another is the "key pinch" where the thumb pad is pressed to the lateral aspect of the middle phalanx of the index finger. Strength is measured by the user executing the pinches on a pinch meter.

Normative values for various physical abilities can be important resources in helping designers understand the capabilities of target end user. A number of studies have investigated values for grip, pinch, and other measures of UE function. Many have focused on establishing and verifying normative values for healthy adults. Others have studied specific populations, such as children (Poole et al. 2005) or those with loss of dexterity following a stroke (Ada et al. 1996).

In order to design products where the required user interaction does not present a barrier to use, it is important to understand which particular aspects of dexterity are most important in the performance of a desired task. This can allow the product to be designed so that it does not require certain physical actions and/or provides a substitute for required actions that the end user might not be able to perform. While normative data for various measures of dexterity exist, these relationships are not known which can limit their utility to a designer as a tool to avoid barriers to use. This paper investigates the relative values of the UE functions in eight products designed for a specific task.

## 2 Method

The data presented here were collected as part of a study to investigate the effect that different types of input provided during the course of designing a new product have on an end user's opinion of the usability of the finished prototype (Choi 2011). Eight new devices were designed (each by an independent design team) with the single goal of aiding a user with limited dexterity to perform the task of taping a box closed. Each team received the same design brief outlining the product use scenario and information about dexterity. The only difference between teams was the additional information they were allowed to gather and use (some were allowed no additional data, some were allowed only textual research, some were allowed only simulation and some were allowed only input from users). Twenty people with limited dexterity were recruited to evaluate the resulting devices. Limited dexterity was defined as reduced ability in grasping, holding, squeezing, or fine finger manipulation. Participants were recruited primarily from the CATEA Consumer Network (Choi et al. 2008) and other disability specific organizations in Atlanta, Georgia. Participants were eligible if they were aged 18 years or older, had a dexterity limitation and did not have a sensory limitation (i.e., hearing or vision).

Each potential participant was prescreened using the DASH survey: disabilities of the arm, shoulder, and hand (IWH 2009). The DASH was developed to provide a quick, self-administered measure of symptoms and functional status (Hudak et al. 1996). It is a 30 item survey that asks the taker to rate their ability to perform various activities of daily living. Scores can range from 0 (a person has no difficulties in performing any of the tasks) to 100 (a person is unable to perform any of the tasks at all). The scores were used to help ensure that participants represented a wide range of functional abilities.

Before evaluating the devices, measurements were taken of each participant's grip strength, key pinch strength, tip pinch strength, and performance on the NHPT. Three measurements of the grip, key pinch, and tip pinch strength were taken for each hand using a Jamar dynamometer and averaged for each hand. The NHPT was performed twice by each participant: once with the left and once with the right hand. Each participant identified their dominant hand during recruitment.

After performing the dexterity tests, each participant evaluated each of the eight new devices. The evaluation consisted of using each to perform the task of taping closed an identical box which was pre-loaded and placed next to it. The task was timed from the moment the evaluator touched the device to begin the task to the moment that sealing the box was completed or the participant gave up. A standard gun style tape dispenser was always evaluated first to provide a point of reference for how well the studied devices performed in comparison. The studied devices were then evaluated in a randomly assigned order.

A usability survey was completed immediately after the task was finished or attempted with each device. The survey itself is reported in (Choi 2011). It is a Likert item survey designed to capture the evaluator's opinion about the level of effectiveness, satisfaction, safety, ease of use, comfort, and other major components of usability. It was based on the existing USE Questionnaire (Lund 2001) and System Usability Scale (Bangor et al. 2008) and validated prior to the study. At the very end, participants were asked to rank each device in order from best to worst based on their opinion. Each device was given a name for internal reference (it was not used with participants) based roughly on how it was setup or operated.

The pole device (Fig. 1a) is made up of a "shelf" that travels up and down a pole and can be rotated to the left or right. The shelf contains a pair of "arms" that hold down the flaps on a box. The arms are powered and can be extended and

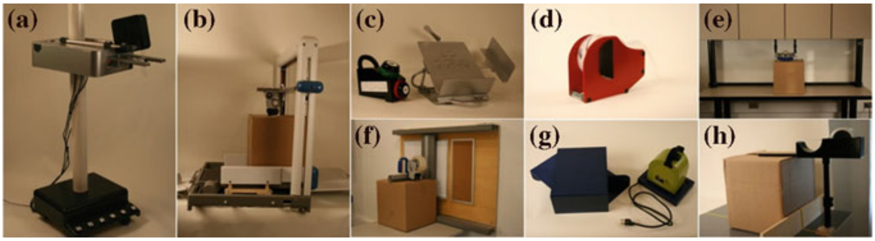


**Fig. 1** The devices used in the evaluation. **a** The pole, **b** the conveyor, **c** the feeder, **d** the puller, **e** the cabinet, **f** the wall, **g** the stamper, and **h** the pole device

retracted as needed. A tape dispenser unit is located on the top of the shelf and is attached to manual telescoping arms. A cutting blade located on the bottom corner of the tape dispenser cuts the tape when the dispenser is rotated. All of the powered operations can be controlled from foot buttons on the base of the device. The device rolls on locking casters so that the user can roll it into position, adjust the taping shelf using the foot controls, hold down the box flaps by extending the arms and lowering the shelf. Tape is dispensed to the top by affixing the exposed part of the tape to the side of the box and pulling the dispenser over the top. Operation requires the use of pinch or key grip to attach the tape and power grip for operating the dispenser.

The conveyor device (Fig. 1b) allows a loaded box to be placed on a small conveyor belt which pulls the box under a tape dispenser mounted on a horizontal platform. This can be moved up and down by using a blue-colored handle that is integrated into the vertical support. Guides on the side of the conveyor can be adjusted to the width of the box via a second blue-colored handle. The tape is affixed to the leading edge of the box and the belt pulls the box under the dispenser causing tape to be applied to the center. A spring mechanism on the dispenser causes a blade to cut the tape once the box has passed through the device. Operation requires the use of pinch or key grip to attach the tape and power grip for adjusting the dispenser height.

The feeder device (Fig. 1c) is designed to sit on the edge of a table and dispense tape in 3-inch increments by pressing a green “Dispense” button on top of the unit. When the desired length of tape has been dispensed, it is cut free by pressing a red outlined “Cut” button on the front of the unit. The dispenser has a small lip that extends down on the front of the device. This provides an opening for the tape to come out and also prevents the unit from sliding away from the user when the dispense button is pressed. After the tape is cut, the user can then place it on the desired area of the box. Operation requires the use of pinch or key grip to grasp the tape and place it on the box.

The puller device (Fig. 1d) is operated by inserting one hand into the central hand hold. The end of the tape is then attached to the edge of the box. The dispenser is then pulled across the top of the box to dispense the tape. There are a series of rollers around the outside of the dispenser to help make the dispensing of the tape more smooth. A cutting blade is attached behind the last roller that cuts the tape with a downward motion to bring the blade in contact with the tape. Operation requires the use of pinch or key grip to attach the tape and power grip for operating the dispenser.

The cabinet device (Fig. 1e) is a dispenser unit mounted under a cabinet or shelves. Telescoping arms allow the height to be adjusted and tracks under the cabinet allow the front-to-back position to be adjusted. Tape is applied to the box by sliding it across the table surface under the dispenser. A curved plastic guide presses the tape down onto the box as it passes under. Pulling downward causes a blade attached to the rear edge of the plastic guide to cut the tape after the box has passed under the dispenser. Operation requires the use of pinch or key grip to attach the tape and power grip for aligning the dispenser.

The wall device (Fig. 1f) consists of a tape dispenser which is mounted on tracks that allow the dispenser to be moved up, down, forward, or backward to align the tape with a box. The leading tape edge is affixed to the box and the dispenser is pushed over the top. When the dispenser reaches the back edge of the box, it naturally slides down, which brings a blade in contact with the tape to cut it. Operation requires the use of pinch or key grip to attach the tape and power grip for operating the dispenser.

The stamper device (Fig. 1g) is a handheld device with a Velcro strap and button on the top that can be used with one hand. To use, the stamper is placed directly on the location where tape should be dispensed. The tape is then "stamped" onto the box when the button on the top is pressed. Operation is not dependent on power grip, key, or tip pinch.

The table device (Fig. 1h) is designed with a tape dispenser component attached to a telescoping pole mounted to a table or other workspace. A dowel extending from the dispenser holds down the box flap on the far side of the user. A low cutout on the dispenser allows a user to put a hand under the tape, sticking it to the top of the hand, and then lift and pull the tape across the top of the box. The user's arm will naturally hold down the box flap nearest to them. Affixing the tape to the far edge of the box with a downward motion also unsticks the tape from their hand. The strip of tape is pressed down against the box, starting on the side farthest from the dispenser. The tension created causes the tape to be cut by a small blade on the top edge of the dispenser. Operation requires the use of pinch or key grip to attach the tape.

## 3 Results

The dexterity measurements were correlated with the usability scores, the task times, and the user's product rank for each of the devices across all study participants. Data collected for task time (s), NHPT (s), grip (kg), key pinch (kg), and tip pinch (kg) are continuous data. Data collected for the usability score and product rank are ordinal data. Pearson's (r) correlation was used for comparisons

**Table 1** Pearson's ($r$) correlation where $p < 0.05$ between task time for each product and participant dexterity measurements

| Task time ($r$) | | | | | | |
|---|---|---|---|---|---|---|
| Measurement | Cabinet | Wall | Stamper | Pole | Feeder | Control |
| NHPT-D | 0.65 | 0.46 | 0.51 | −0.53 | 0.49 | 0.52 |
| NHPT-ND | 0.69 | | | | 0.67 | |

The conveyor, table, and puller products showed no significant correlations

**Table 2** Spearman's rho ($r_s$) correlation where $p < 0.05$ between product rank for each product and participant dexterity measurements

| Product rank ($r_s$) | | | |
|---|---|---|---|
| Measurement | Conveyor | Wall | Table |
| DASH | −0.54 | | |
| NHPT-D | −0.55 | | |
| NHPT-ND | −0.54 | | |
| Grip-ND | | | −0.5 |
| Tip-ND | | | −0.46 |
| Key-D | | −0.5 | |

The cabinet, stamper, puller, pole, and feeder products showed no significant correlations

involving all continuous data. Spearman's rho ($r_s$) correlation was used for comparisons that included strictly ordinal data.

No significant correlations were found between the usability score and the dexterity measurements. Significant correlations ($p < 0.05$) were found between the measured task times and some of the dexterity measures as shown in Table 1. Some significant correlations were also found between the product rank and the dexterity measures as shown in Table 2.

A number of study participants had mobility limitations along with their dexterity limitation. Thus, the data were also divided into dexterity only and dexterity+mobility groups. Correlations between the dexterity measures and usability, task time, and rank were examined for each group. Tables 3, 4, 5, 6, 7, and 8 show the significant correlations ($p < 0.05$, $p < 0.001$ indicated by **) that were found.

## 4 Discussion

The most consistent overall correlation between physical ability and the devices in this study was between the NHPT measurement of the user's dominant hand, and the task duration. Intuitively this makes sense. Longer times for the NHPT indicate less dexterity. A positive correlation might generally be expected since a lower level of dexterity should cause the task to take longer to perform. The pole product

**Table 3** Spearman's rho ($r_s$) correlation where $p < 0.05$ between usability score for each product correlated and participant dexterity measurements for non-wheelchair participants

| Usability score ($r_s$) | | | |
|---|---|---|---|
| Measurement | Wall | Table | Pole |
| NHPT-ND | | 0.58 | 0.6 |
| Tip-ND | –0.64 | | |

The conveyor, cabinet, stamper, puller, feeder, and control products showed no significant correlations

**Table 4** Pearson's ($r$) correlation where $p < 0.05$ between task time for each product and participant dexterity measurements for non-wheelchair participants

| Task time ($r$) | | | | | |
|---|---|---|---|---|---|
| Measurement | Cabinet | Wall | Table | Pole | Control |
| DASH | 0.68 | | 0.65 | 0.76** | |
| NHPT-D | | 0.66 | | 0.71** | 0.52 |
| NHPT-ND | | 0.52 | | | 0.67** |

$p < 0.001$ is indicated by **. The conveyor, stamper, puller and feeder showed no significant correlations

**Table 5** Spearman's rho ($r_s$) correlation where $p < 0.05$ between product rank for each product and participant dexterity measurements for non-wheelchair participants

| Product rank ($r_s$) | | |
|---|---|---|
| Measurement | Puller | Pole |
| NHPT-D | | −0.6 |
| Tip-D | −0.77 | |

The conveyor, cabinet, wall, table, stamper, feeder, and control products showed no significant correlations

**Table 6** Spearman's rho ($r_s$) correlation where $p < 0.05$ between usability score for each product and participant dexterity measurements for wheelchair participants

| Usability score ($r_s$) | | | |
|---|---|---|---|
| Measurement | Wall | Stamper | Puller |
| NHPT-D | | | −0.76 |
| Grip-ND | 0.74 | | |
| Key-ND | | −0.72 | |

The conveyor, cabinet, table, pole, feeder, and control products showed no significant correlations

was an exception with a negative correlation, suggesting that users with better dexterity actually have a more difficult time using it.

Though each of the products in this study was designed specifically with dexterity limited end-users in mind, more correlation between the physical

**Table 7** Pearson's ($r$) correlation where $p < 0.05$ between task time for each product and participant dexterity measurements for wheelchair participants

| Task time ($r$) | | | |
|---|---|---|---|
| Measurement | Conveyor | Wall | Control |
| NHPT-D | | | 0.52 |
| NHPT-ND | 0.72 | 0.72 | 0.67 |
| Grip-ND | | 0.74 | |
| Key-D | 0.75 | | |
| Key-ND | | 0.71 | |

The cabinet, wall, table, puller, pole, and feeder products showed no significant correlations

**Table 8** Spearman's rho ($r_s$) correlation where $p < 0.05$ between product rank for each product and participant dexterity measurements for wheelchair participants

| Product rank ($r_s$) | | |
|---|---|---|
| Measurement | Conveyor | Stamper |
| NHPT-D | −0.82 | |
| NHPT-ND | | −0.73 |

The cabinet, table, puller, pole, feeder, and control products showed no significant correlations

measurements of dexterity and the evaluations of the products was expected. From a designer's perspective it would be valuable to know what kind of an effect a particular component of dexterity such as key pinch has on the usability, efficiency, or user preference for a product. It would have been especially helpful to find correlations among grip, key pinch, and tip pinch strength as normative values are available for these measurements. Even though norms are based on measurements from populations without any specific limitations, they can provide a baseline guide of reasonable expectations. So if it were found that key pinch is especially important to the task of taping a box, a designer can begin with the normative expectation for key pinch force and reduce it so that any key pinch force required in a product is at an appropriate level for the target users.

Correlations with many of the standard dexterity measures did not emerge in this study. This could be due to a number of reasons. It is possible that each of the eight design teams did a good job at removing any significant need to use grip, key pinch, or tip pinch. This explanation seems unlikely due to the fact that the standard tape dispenser did not show any correlation with these traits (it at least requires a power grip) nor did the new devices show consistent correlation.

Several of the participants had other limitations. The most common were mobility limitations. Eight participants were confined to a wheelchair (either manual or powered). In some cases, this could have a major impact on the way that the user interacted with and actually attempted to use the product. The performance of wheelchair and non-wheelchair users was analysed separately. Even in this analysis, there is no consistent dependency among grip, key, or tip pinch strength for either wheelchair or non-wheelchair users performing the tasks.

The best measure that correlated with the task performance (efficiency) was the NHPT, particularly the NHPT score for the dominant hand. As opposed to the grip, tip, and key pinch measures, better scores on the NHPT (i.e., faster times) require aspects of upper body movement as well as gross and fine motor control of the arm, hand, and fingers. Similarly, the DASH measure was correlated with the task time and usability scores of some products. It is also a broader measure of capabilities, although the score is compiled through user self-reporting rather than through an objective test.

The small dataset in this study limits the generalisability of any conclusions. Still the results indicate the possibility that broader measures of ability might be more useful as design aid to predict performance and usability than more atomic measurements such as grip or pinch strength. Even though broad measures like the DASH and NHPT are used often, normative values are not commonly available for large, representative groups of users. Using only these, a designer would not have an easily available reference of the typical capabilities of a particular subset of users. This can be gathered manually just as with more common measures, though collecting a large and representative sample is very time consuming and can be expensive, which makes it less practical. Also, since the DASH and NHPT measures aggregate multiple abilities, the designer is still left with the problem of not knowing which component of a user's ability might impact their use of a product. The specific way that a task is accomplished by a device is obviously greatly influenced by how the interface/interaction with the user is designed. As evidenced by the products made by the design teams in this study, the same task outcome can be achieved in a vast array of completely different ways. Even with a DASH or NHPT score, without understanding how the individual components that make up the score might influence interaction with a product, they are not very useful in identifying barriers that a user might encounter in a designed product.

## 5 Conclusion

Commonly available ergonomic measurements such as grip, key pinch, and tip pinch strength, while clearly components of dexterity, do not alone appear to be reliable predictors of product design outcomes such as usability or task efficiency. Even for a specific task such as taping a box closed, the user's interaction with the product involves many other factors that these individual measurements do not capture. More broad measures of dexterity, such as the DASH and NHPT, both appear to be much better at predicting how well a user might or might not be able to perform a given task with a device. These broader measures might be useful for evaluating the performance of a product for a group of users after it has been designed. They are more limited as a design tool since they are not typically available for broad and representative groups of users. They also cannot inform a designer on whether individual aspects of the physical interaction with a product might pose a barrier to use because they aggregate many types of interactions into a single measurement.

Further study would need to be done to better understand the role that different components of physical ability play in the performance of specific tasks. It may be found that certain abilities generally affect a broad group of tasks or are specific to particular ones. There are other ergonomic measurements, such as wrist strength, that can affect dexterity that were not considered in this study. It would be useful to collect more physical measurements for similar studies in the future, since even a very simple task can involve a much larger number of physical movements. This may help identify already available ergonomic measurements (or combinations of measurements) that might serve as useful design aids for a given task.

Perhaps some different types of measurements could serve as useful aids. As the relationships between particular physical actions and the impact on associated tasks are determined, more effective ways of measuring them might be derived. As the DASH measurement shows correlations with the product performance in this study, it may be possible to devise a reliable way to identify attributes that pose use of barriers through self-reporting, rather than direct physical measurement, allowing relevant data to be collected more quickly, widely, and inexpensively.

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