GESTURE INTERFACING FOR PEOPLE WITH DISABILITY OF THE ARM, SHOULDER AND HAND (DASH) FOR SMART DOOR CONTROL: GOMS ANALYSIS

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ABSTRACT

People with disabilities may interact with their environment differently from other human beings. This is also the case with people with the disability of the arm, shoulder and hand (DASH). However, most environments do not include supportive design for DASH. This study aimed to explore and analyze the body parts used by people with DASH to open doors in a real-world environment and to find an efficient interface design for people with DASH to open doors through a computer interface. This study was conducted in three parts: interviews of three people with DASH, observation of the videos of people with DASH opening doors, and GOMS analysis of five designed interfaces for people with DASH to open doors/windows through a computer interface. It was found that head gesture was suitable to be used as an interaction medium and through the GOMS analysis that the Type 5 (every task has a different head gesture movement) and Type 3 (positioning heads at different vertical or horizontal positions) are two most efficient designed interfaces for head gesture with regards to opening a door.

Keywords: DASH, GOMS, Human Computer Interaction, Gesture Interface, Smart Door

1.0 INTRODUCTION

Humans without any physical disability have limbs that are used to execute their daily work. This may include waking up from bed, wearing clothes, opening doors, and other activities that are predominately done through interaction with their hands. However, human beings born physical impairments to their limbs have different ways of interaction within their daily lives. People with a physical disability of the arm, shoulder and hand (DASH) have difficulties executing many tasks. These tasks include buying food and drinks through vending machines, interacting with computers and mobile phones, and pressing buttons. Many assistive technologies have been developed to assist people with DASH to interact with the environment. The related studies supporting DASH have focused on the automation of objects for their mobility [1]. These include replacement technologies such as an exoskeleton, robotic arms or a prosthetic arm are among the common solutions for assisting people with DASH [2]. An alternatives approach to this problem is through brain computer interfacing [3], i.e. controlling interfaces by thinking of accomplishing the task or interfacing through the eye gaze [4].

Another possible method of interaction for DASH is gestural interaction. Gestural interaction is the use of the human body, typically hand movements, but in some cases those of other limbs to interact with a computer. It is still in its infancy as compared to the research and development of gestural interaction in games technology such as that demonstrated in the X-box [5]. However, Yoda, Ito and Nakayama [6] outlined a comprehensive study on people with DASH, specifically motor dysfunction, i.e. cerebral palsy, quadriplegia or traumatic brain injury. They collected gestures of people with motor dysfunction and classified them for further analysis. The aim of their study was to develop a low-cost gestural interface for people with motor dysfunction to interact with the computer and they classified gesture data from 36 participants. However, their study focused on the recognition system of the head, finger and a simple differential recognition module. Thus far, to the best of our knowledge, no interactive module has been developed for the people with DASH.

1.1 Motivation

This study focused on the interaction of people with DASH, which included people with motor dysfunction and people with a physical disability of the limbs, with a computer interface. In the context of living at home, technology can support people with DASH to function independently. The challenge of providing this independence in all the homes for people with DASH may be difficult to tackle; however, a smart home technology should address and support these issues. The focus of this study was on gestural interaction for universal accessibility, which included people with DASH in a smart built environment, such as in homes and offices. This is in accordance with the suggestion of Suryotrisongko, Kusuma and Ginardi [7] to build a friendly smart city design for people with disabilities, consisting of an accessible, safe, problem solving and flexible environment.

In the context of accessibility, one of the frequent tasks that humans perform is opening doors. Humans are typically required to either push or pull the door to use their hands to open or close the door. People also interact with doors whilst performing a range of everyday activities, including preserving food in refrigerators, heating food in microwaves and washing clothing in washing machines. In terms of safety in a smart built environment, doors need to be secured from unwanted intruders. Smart door locks play an important role in the smart home system, not only as the door guardians but also for a family member's incoming/outgoing awareness [8]. In the contemporary living environment, most people not only want to maintain privacy and security but also try to avoid losing their keys or passwords for their smart doors at home [9]. Additionally, many would like to own a fast, convenient and cost-effective exclusive door lock controller. This should include the security and functionality of both new and already installed doors.

1.2 The aim of the study

The aim of this study was twofold. One was to explore and analyze how people with DASH open doors in a real-world environment. The other was to find an efficient interface design for people with DASH to interact with the computer to open doors. The output of the analysis was a suggested part of body to be used for gestures and a suitable interface design for it. The analysis was conducted using the goals, operators, methods and selection of rules (GOMS) model [10]. The GOMS model analyses an interface from the perspectives of both the users and the objects.

The research questions (RQ) were as follows:

1) How can we identify and measure the disability of people with DASH?
2) How do people with DASH open a door in a real-world environment?
3) What is the most often used body part for people with DASH to open a door?
4) How can we identify suitable gestures to make it easy for people with DASH to control smart doors in smart home environments?
5) What is an efficient way to interact with a computer-designed interface using the abovementioned gestures?

This paper presents a literature review of the existing systems, the work related to the gestural interface for people with DASH, Quick DASH, and the research methodology, including the GOMS analysis, results and discussion, and finally, the conclusion.

2.0 LITERATURE REVIEW

2.1 DASH Human- Computer Interaction

Research in human–computer interactions has been conducted for people with DASH. The existing techniques, research and experiments can be categorized into three main areas, namely the body machine interface, the speech recognition interface and the electromyography (EMG)-based interface.

One of the studies included a body machine interface, which is modular and can be easily adapted to the residual functional capacities (RFCs) of different users [11]. This body machine interface reads the user's head and shoulder motions as well as his/her residual myoelectric activity and translates them into control commands. The speech recognition system was developed with the capability of understanding the specific context of sentences, words and commands [12]. This system is sufficiently flexible to let the user input his/her voice and control all the web application text available on a web server as well as help with web reading.

In contrast, EMG is a technique for encoding the electrical activity produced by skeletal muscles. EMG-based computer access devices use biological signals [13] and decode the upper-limb gestures from EMG signals. These systems can help to develop human–computer interactions that increase the quality of life through the inclusion of the disabled or elderly people. Another study designed a device for people who lost the ability to perform movement with their fingers and precise movements of the wrist [14]. A Microsoft Kinect device was used to detect the user movements from the waist up.

Fall *et al.* [15] developed a wearable control interface for people who have a weak arm, hands and fingers or are unable to control these body parts but have the ability to control their head/head-part and shoulder. Aguiar and Bó [16] developed a wearable EMG-based system for people with upper limb disabilities. Altakrouri, Burmeister, Boldt and Schrader [17] developed a similar system for people suffering from hand and arm impairment.

Yoda, Ito and Nakayama [6] performed an experimental study on people with severe motor dysfunction. They developed three types of recognition modules, namely a module for the head, one for the finger and a simple differential module. In the head recognition module, a simple estimation of the head inclination was detected using two-dimensional (2D) recognition engines. They used range images with the aim to not only estimate the head inclination but also combine the recognition of other sites of the subject's upper body. For the finger recognition, the detection of the finger as well as that of the hand was involved. The simple differential recognition module captures the target site as accurately as possible and then learns to recognize the movements of the eye. In this study, they produced a prototype that takes in all the possible gestures of people with DASH, such as specific movement of the mouth, ear and forefingers, as an input.

The research progress for people with DASH using gestures such as those mentioned above should be extended in terms of how these people can be assisted in completing certain tasks. For example, in the context of multiple-domain studies, these possible gestures can help people with DASH to call for an assistant, control electronic appliances, communicate with family and friends or any other task. However, the focus of this study was on how certain gestures can be used to open a door in a smart built environment.

2.2 Doors as Smart Built Environment Accessibility for People with DASH

Supporting people with DASH by providing seamless interactions between them and the environment is crucial in smart built environments with embedded networks through the Internet of Things (IOT). Accessibility and safety are two important standard criteria to be applied in design and development [7, 18, 19]. A smart built utility for people with DASH must be easily accessible and, at the same time, be secured from unwanted intruders. Bota *et al.* described a smart home utility [18] using Cloud IoT that enables the automation of common in-house activities. It enables the transformation of everyday objects into information appliances which are interconnected through the Internet. This smart home is able to monitor the power usage of devices to improve power usage habits or remotely control them, such as manage the lighting, heating and air-conditioning. An important utility element in a smart built environment is doors and similar functional objects such as windows and compartments (such as wardrobes and drawers).

There are many types of doors attached by hinges to a frame. Doors are parts of a space for ingress into or egress from a building, room or vehicle [20]. Doors can also be part of a compartment to access objects in wardrobes, cabinets, safety boxes and electrical appliances such as refrigerators, microwaves, washing machines and dishwashers. The door panel may be moved in various ways such as at angles away from the frame, by sliding on a plane parallel to the frame or by folding in angles on a parallel plane to allow or prevent ingress or egress. Compartment doors in electrical appliances may also have buttons that need to be pushed to allow access to objects or space. Doors can also have knobs such as handles that we need to turn, lever handles that we need to push down to activate a certain mechanism and a U-shaped handle that users need to pull a lever [20].

Literature studies have shown that specific interfacing technologies have been developed for different categories of DASH. Therefore, it is essential to categorize the people with DASH according to parts of arms, shoulders and hands as they will have different capabilities.

2.3 Categorization of DASH

In order to help people with DASH to perform their daily tasks, specifically opening and closing doors, we need to identify the DASH category. This is because some of them have a disability with their hands but can still manage to open doors and grab objects using their elbows and shoulders. There are also cases where they have arms, but their limbs are not very strong.

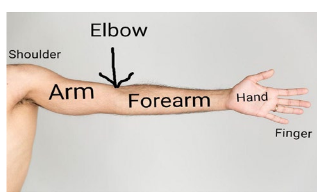


Fig. 1**:** Category of DASH

TABLE 1 Analysis of the type of DASH category with the corresponding possible part of body for interaction

DASH category	Possible interaction medium				
	Use part of hand	Use part of forearm	Use part of elbow	Use part of arm	Other parts of body
No finger - C1	✔	✔	✔	✔	✔
No hand - C2	X	✔	✔	✔	✔
No forearm - C3	X	X	✔	✔	✔
No elbow - C4	X	X	X	✔	✔
No arm - C5	X	X	X	X	✔
No shoulder - C6	X	X	X	X	✔

Fig. 1 and Table 1 show the DASH categories, consisting of five possible gesture interaction mediums with six body parts. The five possible gesture interactions are with a part of hand, part of elbow, part of arm and any other part of the body. Examples of the other parts of the body that can be included as a medium for gestural signals are the tongue, head, the legs, eyes and the brain.

The categorization of this disability was first conducted by Yoda, Itoh on Nakayama [6] in their research study on gesture interfaces for persons with motor dysfunction who could not use interface switches. They categorized body parts for the gesture-based input into four groups, namely hands and arms, head, legs and shoulders.

2.4 Quick DASH

Quick DASH is a self-reporting questionnaire for patients with one or more disabilities of the arm, shoulder and hand [21]. It contains 11 questions that rates physical function and symptoms in people with upper limb musculoskeletal disorders. The purpose of using this questionnaire is to know the level of disability and severity. Quick DASH is also used as a scale for patients with the carpal tunnel syndrome (CTS) [15]. The Quick DASH scoring formula is as follows:

$$([(\text{sum of n responses})/n] - 1)\ (25)$$

n = number of completed activities done by the participant

Quick DASH questions an individual's ability to do activities irrespective of the arm, shoulder or hand he/she uses. This questionnaire is used to validate the visual analogue scale pain, pinch and grip strength tests. The score ranges from 0 (no disability) to 100 (most severe disability). The Quick DASH score can be used to provide information on the requirement needs to develop a system for the disabled to perform a gesture according to their ability. This is because some disabled people have their limbs, but the Quick DASH score shows severe disability. Therefore, in terms of the body part functionality, these people should lie within the same category as people with no limbs.

3.0 METHODOLOGY

The aim of this study was to explore and analyze the body parts used by people with DASH to open doors in a real-world environment and to find an efficient interface design for people with DASH to open doors through a computer interface. Fig. 2 shows research methodology outlined to meet the research objectives. In all, six people were interviewed and observed in accordance with Creswell, who stated that the sample size of a phenomenon qualitative study should be between 5 and 25 [22, 23]. However, Baboucarr (2014) stated that six participants were suited to obtain information [23]. This research is approved by the University of Malaya Research ethics committee with reference no: UM.TNC2/UMREC-557

The analysis of each of the parts of this study used the goals, operators, methods and selection of rules (GOMS) model. The GOMS model analyses an interface from the perspectives of both the users and the objects [10]. The GOMS model is used to describe a task and the user's knowledge towards it and can be used to predict the time required to execute a certain task. This prediction is very useful for making decisions of adopting certain interface designs. GOMS is described using the KLM-GOMS notation [24]. The tasks were described for each step according to the goal of the tasks that were decomposed to the lowest level in terms of operation. The number of operations involved for each task could be used to predict the efficiency of the tasks involved.

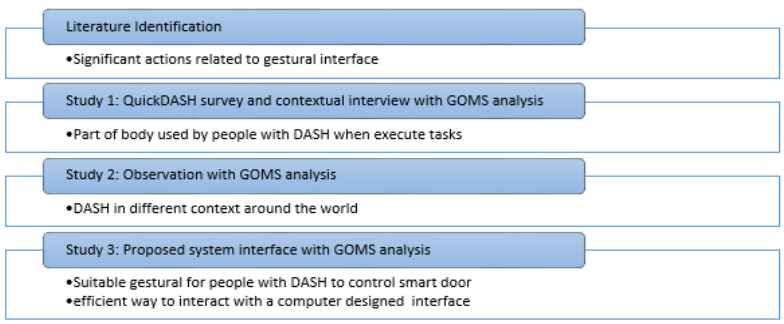


Fig. 2 Research methodology and output

3.1 Literature Identification

This study covered data in research articles published in academic journals between the years 2011 and 2018. The data were retrieved individually from the Web of Science database. Meanwhile, the search was conducted using several keywords: 1) 'arm' AND 'hand' AND 'disability', 2) 'disable and gesture interface', 3) 'gesture interface', 4) 'hand gesture', 5) 'Kinect' AND 'gesture' AND 'disabled', 6) 'smart cities' AND 'disabled', 7) 'gesture' and 'voice', 8) 'IOT' and 'smart environment'. Only the data relevance to this study were included. From the literature identification, we identified the significant actions related to a gestural interface in terms of computing and the living environment. The common gestural interface identified were the use of hands followed by vision-based and head gesture interfaces.

3.2 Study 1: Quick DASH Survey and Contextual Interview with GOMS Analysis

Participants

Interview sessions were conducted with three people with DASH to fill out a questionnaire. The participants were as follows: participant 1 (P1), a 53-year-old male in category C3 with right hand disability; participant 2 (P2), a 15-year-old female in category C6 with disabilities of both hands; and participant 3 (P3), a 13-year-old female in category C6 with right hand disability.

Procedure

All the participants were referred by friends and relatives among researchers who knew people with DASH. These participants were contacted through phone calls to set up a phone interview appointment. Before the phone interview appointment, they were given the Quick DASH questionnaire. The interview was divided into two sections. First, in our study, the Quick DASH questionnaire [14] was given to the participants. It was used to classify the group of disabled people with DASH. Later, we calculated the disability score using the Quick DASH formula and then categorized our participants. The second interview was a contextual interview specifically asking about opening a door or window and wardrobe door. The objective of asking this question was to extract the details on which body part did the participants use often to execute these tasks.

3.3 Study 2: Observation

First, we searched for YouTube videos using the following keywords: 'no limbs', 'hand disability people use computer', and 'disability people use compute'. YouTube also suggested several videos related to the search keywords. If a video was related to these categories, we include it in the list of videos to be observed. In particular, we observed the YouTube videos of people with DASH opening doors. There were many videos of people with DASH; however, those that included a snapshot of them opening doors were very limited.

We observed three YouTube videos in all: participant 4 (P4) belonged to the category of C5 for both hands, and P5 and P6 belonged to the category of C6 for both hands. We differentiated these videos according to the category of people with DASH and the body part they used to execute a task. We also observed different views on the context of DASH people using assistive technology, gesture and other tasks that they could execute. The advantage of the YouTube observations was the ability to observe people from different countries and view the technology developed specifically for people with disabilities.

3.4 Study 3: Proposed System Interface with GOMS Analysis

The results of the study parts 1 and 2 led to the decision to choose head gestures for people with DASH to control smart objects at home, such as doors, windows and compartments through a computer interface. The designs of five types of interactive interfaces were created. A GOMS analysis was conducted for each of the interfaces to determine the interaction efficiency of the designed interface.

The five types of interfaces were designed using head gestures for use in smart homes. The proposed design consisted of the same functionality but different ways to execute a task. We decided to use head gestures because the head is the most often used body part and to position gestures using the head was deemed appropriate and polite as compare to using other parts of the body, such as mouth, jaw, shoulder and toes. This is specific to people with DASH. There are six proposed directional head movements, namely yaw (turn head left/right), pitch (nod the head up/down), roll (tilt the head left/right), circular top (moving the top of the head clockwise/anticlockwise) and circular front (moving the front of the face) clockwise and anticlockwise (see Fig. 3). In total, the head gestures could generate 12 single gestures, and from these, a combination of two or more could generate more combined head gestures.

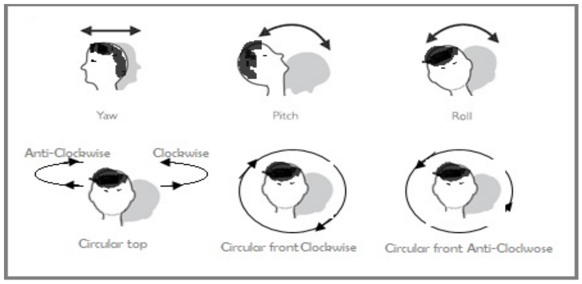


Fig. 3: Directional head gestures

Five types of interfaces (T1–T5) were designed to enable people with DASH to interact with the computer to open doors, windows and compartments. Fig. 4 shows the paper prototype of the interfaces. The control of the interfaces was via button clicks (where all the objects in the interface were clickable) or directly through head gestures. There were two types of navigation. One was through buttons via cursor movement using one of the head gestures shown in Fig. 3. The other was directly through head gestures, i.e. one gesture for one specific task. Each interface started with a main page showing all the rooms in the house and two other options, namely open/close all the windows and doors of the rooms. The other subsequent pages were for opening/closing doors, windows or compartments in a specific room. Finally, the head nod (pitching gesture) was used to select/click the button/icon.

The interfaces were designed with a few common features within the X × Y grid. First, the top-most right corner of every page had the label for the current page; below it was the exit button, gesture instruction and navigation direction. Second, for each room page, the top-most line of the page had the open and close mode button/icon. Below it was the home button and the exit button. A further description of the above-mentioned types of interfaces is as follows:

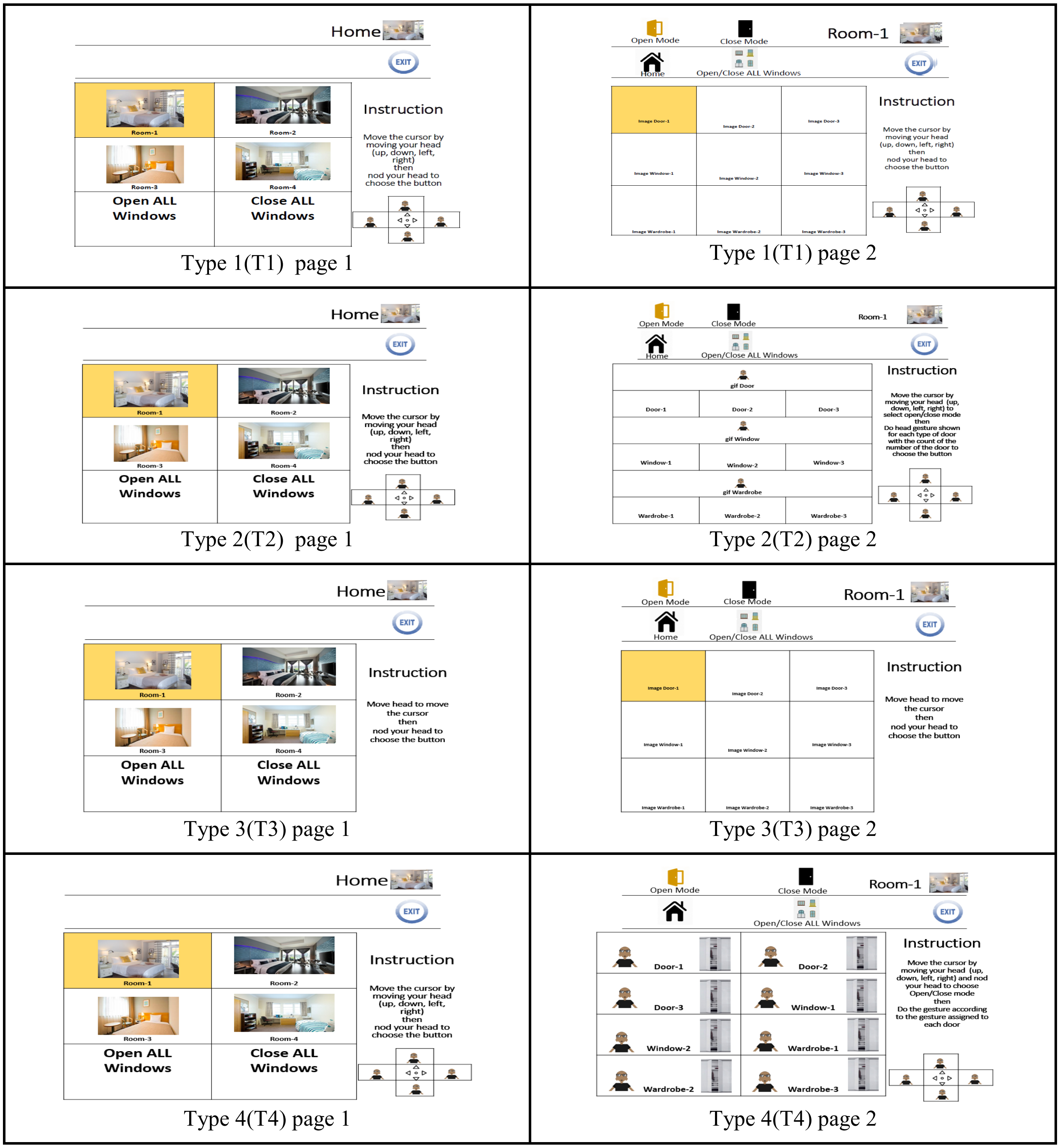
- ●Type 1 (T1): The roll and pitch head gestures (left, right, up or down) determine the direction of the navigation of the cursor, and then, the head nod is used to select the button.

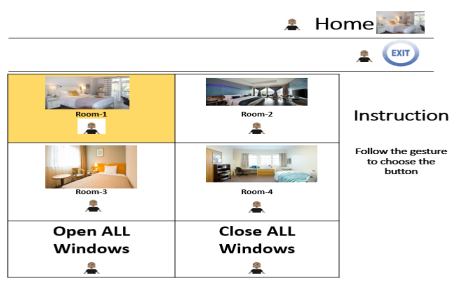
- ●Type 2 (T2): It involves the roll and pitch gestures for navigation in the top menu and to select a door/window, a predetermined gesture movement is used. To select a specific object, the predetermined gesture is repeated depending on the ID number of the object to be chosen. For example, window 1, id number = 1, do gesture only once. For window 2, id number = 2, do gesture twice.

- ●Type 3 (T3): Users are required to position their heads at different vertical or horizontal positions with respect to the object display position in the interface, and then, use the head nod to select an object.

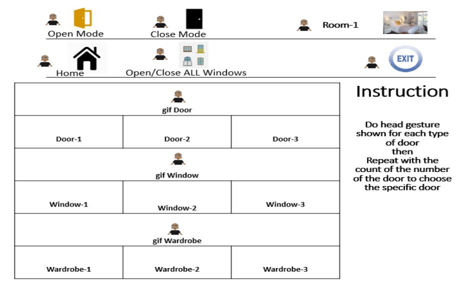
- ●Type 4 (T4): The roll and pitch head gestures (left, right, up or down) determine the direction of the navigation of the cursor in the Main Page. To open/close an object, the users need to use different gestures for each object.

- ●Type 5 (T5): Every task has a different head gesture movement; the movement count depends on the door ID.


Home
EXIT
Room-1
Room-2
Room-3
Room-4
Open ALL Windows
Close ALL Windows
Instruction
Move the cursor by moving your head (up, down, left, right) then nod your head to choose the button
Type 1(T1) page 1
Open Mode
Close Mode
Room-1
Home
Open/Close ALL Windows
Type 1(T1) page 2
Type 2(T2) page 1
Door-1
Door-2
Door-3
Window-1
Window-2
Window-3
Wardrobe-1
Wardrobe-2
Wardrobe-3
Type 2(T2) page 2
Move head to move the cursor then nod your head to choose the button
Type 3(T3) page 1
Type 3(T3) page 2
Type 4(T4) page 1
Move the cursor by moving your head (up, down, left, right) and nod your head to choose Open/Close mode then Do the gesture according to the gesture assigned to each door
Type 4(T4) page 2



Type 5(T5) page 1



Type 5(T5) page 2

Fig. 4: Paper prototype of the interfaces (T1 - T5)

4.0 RESULTS AND DISCUSSION

In this section, the results of the interviews, observations and GOMS analysis are reported.

4.1 Study 1: Interview with people with DASH using GOMS analysis (Answering RQ1)

Table 2: Interview questions

No	Questions on opening a door	Interview input		
		P1	P2	P3
1	-How do you open doors? -Do you ask someone to help you? -Do you need any tools to do so?	-If it is a lever door, I use my forearm to pull the door. If doing so is difficult, I pull it with my left hand instead. -No. Usually, I do it by myself. -No.	-I use my shoulder and jaw. -I can do it myself. -I use my face/shoulder to push.	-I'm left-handed since birth, and use it to open doors. -No, because I do it by myself. -No.
2	-How do you open the wardrobe door? -Do you ask someone to help you? -Do you need any tools to do so?	-I use my left hand instead. -I do it by myself. -No.	-I use my foot. -Sometimes, I need help. -No.	-I prefer to use my left hand. -No. -No.

Table 2 presents a summary of the interview session with three participants with DASH. For opening a door, the participants P1 and P3 preferred to use their perfect hand and seldom sought help or used any tools while opening doors. P1 belonging to category C6 preferred to use his shoulder and jaw. For opening the wardrobe, P1 and P3 used their left hands. P2 used her foot or sometimes, asked for help to open the door. The results for the Quick DASH and the contextual interview (in the form of the GOMS analysis) are presented in Table 3.

TABLE 3 Results for DASH participants

DASH Participant	Quick DASH score	Disability	Goal	GOMS analysis (Tasks Involved)	No. of steps for the lowest-level operation
Person without disability (for comparison)		No disability	Open a knob door (Using hand)	S1: Locate desired door. S2: Locate door handle/knob. S3: Handle knob using hand S3.1: Grab hold of said handle/knob using hand S3.2: Turn door knob 90° clockwise using hand S4: Pull or push door using hand	5
			Open a lever door (Using hand)	S1: Locate desired door. S2: Locate door handle. S3: Handle lever using one hand (left/right) S3.1: pull down said handle using right arm S4: Pull or push door using body	4
P1	72%	Right - C3	Open a knob door (Using left hand)	Same as that for a normal person, but S4 and S5 performed using left hand.	5
			Open a lever door (Using forearm)	Same as that for a normal person, but S4 and S5 performed using forearm.	4
P2	72%	Left, right - C6	Open a knob door (Using shoulder, jaw and body)	Same as that for a normal person, but S4 and S5 performed using shoulder and jaw.	5
			Open a lever door (Using mouth)	Same as that for a normal person, but S4 and S5 performed using mouth.	4

P3	57%	Right - C6	Open a knob door (Using left hand)	Same as that for a normal person, but S4 and S5 performed using left hand.	5
			Open a lever door (Using left hand)	Same as that for a normal person, but S4 and S5 performed using left hand	4

P1 belonged to the C3 category with 72% disability of no finger, hand and forearm on the right side of the body. He could not grab and rotate a door knob using his left hand; else, he would have used his left hand. However, in the case of a door with a lever handle, he did not face any such problems, as he could pull down the handle using his left hand. P2 belonged to the C3 category with 72% disability of no hands, arm and shoulders on both left and right sides of the body. When opening a door, P2 used the shoulder and jaw to grab the knob. This act caused P2 some discomfort, as she had to lower her body to reach the door handle. P3 belonged to the C6 category with 57% disability of no arm, shoulder and hand on the right side of the body. Her problem was that when she carried things using her left hand, she had to put these things down before being able to open a door or had to just ask someone else for help.

People without any physical disabilities take five steps to open doors with knobs and four steps for opening doors with lever handles. The same was the case for P1, P2 and P3. The difference was in the body part used to execute the task. Overall, the GOMS analysis revealed that the differences were in S4 and S5. It is easy for a person to grab and rotate a door knob but difficult for a disabled person to do so. Ideally, a lever door would be a better design for people with DASH.

4.2 Study 2: Observation with GOMS analysis

Table 4 shows the summary of the YouTube videos of people with DASH opening a door. The GOMS analysis shows that all three participants (P4, P5, and P6) took four steps to open a lever door, similar to people without disability, as shown in Table 3. The only difference was in step 3 in handling a door using a body part.

TABLE 4 YouTube videos of people with DASH opening doors using parts of body.

Observed DASH participant	Disability	GOM Tasks Analysis	Link	No. of steps for the lowest- level operation
P4	Left, right C5 (Using shoulder)	Door push button created for disabled S1: Locate desired door. S2: Locate door button. S3: Handle button using shoulder S3.1: push button using shoulder S4: Push door using body	https://www.youtube.com/watch?v=DpNlvQLgsAc (2:14s)	4
P4	Left, right C5 (Using mouth)	Only for Lever door. S1: Locate desired door. S2: Locate door handle. S3: Handle lever using mouth S3.1: pull down said handle using mouth S4: Pull or push door using body	https://www.youtube.com/watch?v=DpNlvQLgsAc (3:31s)	4
P5 P6	Left, right C6 (Using toes) Left, right C6 (Using toes)	Only for Lever handle door S1: Locate desired door. S2: Locate door handle. S3: Handle lever using right toes S3.1: pull down/up said handle using toes S4: Pull or push door using body	https://www.youtube.com/watch?v=7ylRX14rsA8 https://www.youtube.com/watch?v=iShFfP96e0s	4

As a summary, the three body parts that people with DASH used were shoulder, toes and mouth. P4 belonged to category C5 with a disability of both hands. In the first video, the participant uses her shoulder to push open the door using the door button. The door was designed specifically for disabled people (at 2 min:14 s). P4 also used her mouth to open the lever door. She opened the door by gripping and pulling down the handle and then pushed the door using her body (at 3 min:31 s). Both P5 and P6 belonged to category C6 with left and right disabilities. They used their toes to open the lever door handle. For the execution of tasks using toes, they had to raise their toes to reach the lever handle to pull it down. Managing a door knob was slightly difficult for them as knobs require strong grip pressure to fully turn them.

4.3 Summary of Studies 1 and 2

Table 5 shows the relative position of the body parts involved in opening doors. The most frequently used body parts were at the top-most body position. This indicated that gestural interfacing for people with DASH should focus on designing interactions in this area for better usability and DASH user experience. We chose the head as the body part used for gesture interactions with the computer environment, because the head is the most often used body part to open a door for people with DASH.

Table 5: Body parts involved in executing task for people with DASH

Body Segment	Body Part	TOTAL
Head	Mouth, Jaw, shoulder	3
Abdomen	Arm, elbow, hand (C2-C5)	2
Leg	Toes	2

4.4 Study 3: Designed interfaces with GOMS analysis

Table 6 presents the GOMS analysis for each of the Type 1 - Type 5 interfaces.

TABLE 6 Proposed system with GOMS analysis

Type of Gesture	(G1)	(G2)	(G3)	(G4)	(G5)
1. Directional head gesture (T1)	•S1 – Locate the chosen task. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head twice to open the chosen task.	•S1 – Locate the home icon. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to choose home.	•S1 – Locate the icon for open/close mode. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to select the desired icon. •S(4 + N) – Locate the icon to open/close all windows. •S(5 + N + M) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(6 + N + M) – Nod head to select the desired icon.	•S1 – Locate the icon for open mode. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to select the chosen icon. •S(4 + N) – Locate the icon to open chosen image. •S(5 + N + M) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(6 + N + M) – Nod head to select the chosen image.	•S1 – Locate the home icon. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to choose home. •S(4 + N) – Locate the Room 2 icon. •S(5 + N + M) - Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(6 + N + M) – Nod head to select Room 2. •S(7 + N + M) – Locate the icon for open mode. •S(8 + N + M + P) – Move the cursor (up, down, left, right) until the chosen mode button is highlighted. •S(9 + N + M + P) – Nod head to select the mode. •S(10 + N + M + P) – Locate the icon to open Door 1. •S(11 + N + M + P + Q) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(12 + N + M + P + Q) – Nod head to select the chosen image.

2. Combining directional head gesture with specific gesture movement count (T2)	•S1 – Locate the chosen task. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head twice to open the chosen task.	•S1 – Locate the home icon. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to choose home.	•S1 – Locate the icon for open/close mode. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to select the desired icon. •S(4 + N) – Locate the icon to open/close all windows. •S(5 + N + M) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(6 + N + M) – Nod head to select the desired icon.	•S1 – Locate the icon for open mode. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to select the desired icon. •S(4 + N) – Locate the icon to open Door 2. S(5 + N) – Repeat the gesture twice to select Door 2.	•S1 – Locate the home icon •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to choose home. •S(4 + N) – Locate the Room 2 icon. •S(5 + N + M) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(6 + N + M) – Nod head to select Room 2. •S(7 + N + M) – Locate the icon for open mode. •S(8 + N + M + P) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(9 + N + M + P) – Nod head to select the chosen icon. •S(1 +N +M+ P) – Locate the icon to open Door 1. S(11 + N + M + P) – Do the gesture to select Door 1.
3. Positional head gesture (T3)	•S1 – Locate the chosen task. •S2 – Position head at the chosen task. •S3 – Nod head to open the chosen task.	•S1 – Locate the home icon. •S2 – Position head at the home icon. •S3 – Nod head to choose home.	•S1 – Locate the icon for open/close mode. •S2 – Position head at the open/close mode. •S3 – Nod head to select the open/close mode. •S4 – Locate the icon to open/close all windows. •S5 – Position head at the Open/Close ALL Windows button. •S6 – Nod head to select the Open/Close ALL Windows button.	•S1 – Locate the icon for open mode. •S2 – Position head at the open mode. •S3 – Nod head to select the open/close mode. •S4 - Locate the icon to chosen image. •S5 – Position head at the chosen image. •S6 – Nod head to select the chosen image.	•S1 – Locate the home icon. •S2 – Move head to move the cursor. •S3 – Nod head to choose home. •S4 – Locate the Room 2 icon. •S5 – Move head to move the cursor until the Room 2 icon is highlighted. •S6 – Nod head to select Room 2. •S7 - Locate the icon for open mode. •S8 – Move head to move the cursor until the chosen icon is highlighted. •S9 – Nod head to select the chosen icon. •S10 - Locate the icon to open Door 1. •S11 – Move head to move the cursor until Door 1 is highlighted. •S12 – Nod head to select the chosen image.

4. One gesture, one task (T4)	•S1 – Locate the chosen task. •S(2 + N) - Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head twice to open the chosen task.	•S1 – Locate the home icon. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to choose home.	•S1 – Locate the icon for open/close mode. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to select the desired icon. •S(4 + N) – Locate the icon to open/close all windows. •S(5 + N + M) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(6 + N + M) – Nod head to select the desired icon.	•S1 – Locate the icon for open mode. •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to select the chosen icon. •S(4 + N) – Locate the gesture to open chosen image. •S(5 + N) – Do the gesture to select the chosen image.	•S1 – Locate the home icon •S(2 + N) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(3 + N) – Nod head to choose home. •S(4 + N) – Locate the Room 2 icon. •S(5 + N + M) - Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(6 + N + M) – Nod head to select Room 2. •S(7 + N + M) – Locate the icon for open mode. •S(8 + N + M + P) – Move the cursor (up, down, left, right) until the chosen task button is highlighted. •S(9 + N + M + P) – Nod head to select the chosen icon. •S(10 + N+M+P) – Locate the icon to open Door 1. •S(11 + N + M + P) – Do the gesture to select Door 1.
5. Specific head gesture movement count (T5)	•S1 – Locate the gesture for chosen task. •S2 – Do the head gesture to open the chosen task.	•S1 – Locate the gesture for home icon. •S2 – Do the head gesture to return to home page.	•S1 – Locate the gesture for open/close mode. •S2 – Do the head gesture to open/close mode. •S3 – Locate the gesture. to open/close all windows •S4 – Do the head gesture to open/close all windows.	•S1 – Locate the gesture for open/close mode. •S2 – Do the head gesture to open/close mode. •S3 – Locate the gesture to open Door 2. •S4 – Do the gesture twice to select Door 2.	•S1 – Locate the gesture for home icon. •S2 – Do the head gesture for home icon. •S3 – Locate the gesture for Room 2. •S4 – Do the head gesture for Room 2. •S5 - Locate the gesture for open/close mode. •S6 – Do the head gesture to open/close mode. •S7 – Locate the gesture to open Door 1. •S8 – Do the gesture to select Door 1.

Table 8 shows the GOMS analysis of the paper prototype interface designed using head gestures to accomplish five specific goals Goal 1 (G1)–Goal 5 (G5).

G1: Choose a task/room on the home page.

G2: Return to the home page to choose a task/room on the main menu page when the current page is at a particular room.

G3: Open/close all windows in a room when they are in a particular room.

G4: Open/close door/window/compartment in a particular room. The participants have to choose the desired room first from the main menu. After that, choose the open/close mode, and then, choose which door/window/compartment to open.

G5: Open/close a window/door/compartment from another room. Currently, the user wants to go out from Room-1 to open another door from Room-2. The user has to go to main menu by navigating to the home page and then, perform the steps in G4.

The different types of interfaces (T1–T5) produce different operational steps for each of the goals G1–G5. Some goals took more steps, as more operations had to be executed. Fig. 5 shows that the T5 interface takes the least number of steps to achieve each goal, followed by T3, T1, T2 and T4. This is also a general principle that should be adopted in designing any interface with multiple tasks and inline with suggested principles by Nielsen [26] and Shneiderman [27] to reduce the number of interactions and to increase the pace of interaction.

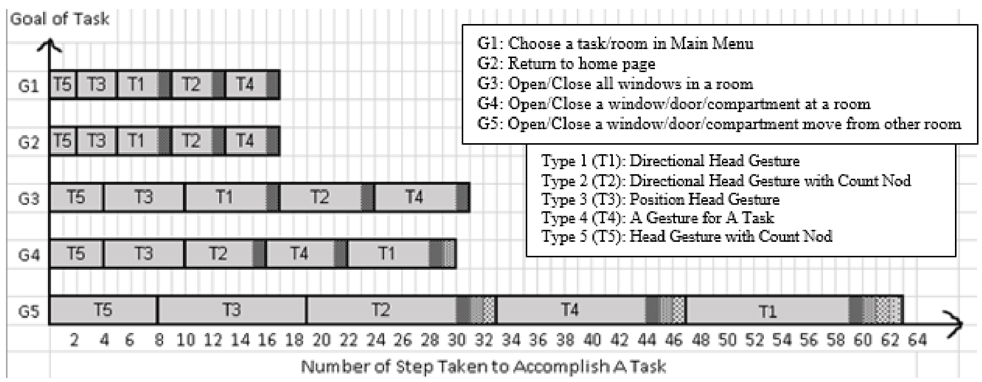


Fig. 5: Ranking of designed interfaces for people with DASH

For G1 and G2, T5 required two steps; T3, required three steps; and T1, T2 and T4 required the same number steps, which was 3 + N. N implied that number of steps depended on the total number of repeated operations to be executed. The larger the number of rooms in the home, the larger was the number of steps needed to move the cursor to a particular room button/icon.

For G3 to open/close all windows in a room, T5 required four steps; T3 required six steps; and T1, T2 and T4 required 6 + N + M steps. N implied number of steps to move the cursor to a particular room, and M implied number of steps to move the cursor to the 'all windows' button until it was highlighted.

For G4, open/close a window/door/compartment in a room, T5 required four steps; T3 required six steps; and T2 and T4 required 5 + N steps. N implied number of steps to move the cursor to a particular room. T1 required 6 + N + M steps. M implied number of steps to move the cursor to a particular window/door/compartment. T1 differed from T2 and T4 because to choose different windows/doors/compartments, different gestures had to be used. In T2, a particular door for the task was selected by the repeated use of the identified gesture depending on the door identification number. For example, if the user wanted to open door 2, the user had to roll (see Fig. 3) his/her head twice to the left. In T4, every door had a different gesture; e.g. the door 2 gesture was to roll the head to the left, and the door 3 gesture was to roll the head to the right. In this interface, the user did not have to move the cursor as in T1 to choose the identified door.

For G5 to open/close window/door/compartment from a different room, T5 required 8 steps, T3 required 11 steps, and T2 and T4 required 11 + N + M + P steps. N is depending on the location of the home page button, as it was located at the top-left line number two; therefore, the user had to repeat the gesture to move the cursor. M denoted number of steps to move the cursor to a particular room, and P denoted number of steps to select either the open or the close mode button. T1 required 12 + N + M + P + Q steps. Q denoted number of steps to select a particular door.

T5 interface required the least number of steps for achieving each of the considered goals. It had a different gesture for every task. This made it easier for the user to do the gesture by ignoring the current cursor location. The users do not need to perform a repeating gesture to achieve a goal. The problem of using head gestures for each task was that only a limited number of gestures are possible using only the head. On the other hand T3 interface, uses different positions (based on x-y coordinates of the control elements in the interface) to capture a head node. It could possibly be a more learnable and memorable interaction type compared to T5, although from the GOMS analysis there will be more steps taken to accomplish the related GOALS.

4.5 Implications on the advantages of using head gesture

There are several advantages of Smart Door Control using head gesture. First, it broadens the choices available on how users with DASH can interact with the environment. Besides using assistive devices such as exoskeleton, robotic arms or a prosthetic arm [2], people with DASH can also utilize existing computer technology which only requires a computer, a web camera and the appropriate head gesture recognition software. This could be considered as a cheaper solution. Secondly, head gesture interaction can be more supportive in regards to maintaining body posture rather than using leg/foot to reach door handle or window. Thirdly, in a study by Edwards [25] whom indicated that contractures, abnormal nail growth, muscle wasting, skin color and temperature change can occur if bad postures and limb immobilization are repeatedly adopted as daily habits. Poor posture habits (muscle imbalance/tension, carry heavy thing, bending and twist leg/hand) can put a lot of stress on the spine, which can result in back pain, muscle fatigue, fatal problem, and other symptoms. Fourthly, head gestures can be considered as a more polite gesture to be executed especially in public spaces in comparison to using the legs or the tongue. Head gestures for Smart Door Control or any other control system can also be used by people without physical disability for multitasking activities such as if their hands are already occupied in controlling the mouse and the keyboard. It is also suitable to be used for injured, post-surgery and elderly people.

5.0 CONCLUSION

People with DASH faced many problems in interacting with the real world and one of the problems is opening a door. This research started with Quick DASH questionnaire to help to identify and measure the disability of people with DASH by knowing their severity and strength of the parts of hand to accomplish a task such as done by C. L. Fall, F. Quevillon, A. Campeau-Lecours, S. Latour, M. Blouin, C. Gosselin, & B. Gosselin [15] to scale patients with carpel tunnel syndrome (CTS). The interface developed by them for people using powered-wheelchairs and proof of concept system implemented and send the signal to assistive robotic arm. Through the studies in parts 1 and 2, we found that the head segment is the most frequently used body part of people with DASH to open doors. This implied that the gestural interface technology for people with DASH should focus on using head segment to design for interactions. From Study 3, we inferred that an efficient interface design for people with DASH was T5 interface followed by T3 because they took fewer steps to accomplish the goals related to opening a door. Our findings, show different ways people with DASH try to achieve the goals, to the extent that they need to use their foot or jaw to handle the door. Similarly, the study of Yoda, Ito and Nakayama on people with DASH aim at developing gesture interface for people with motor dysfunction to interact with computers [6]. However, their study focused on the recognition system of the head, finger and a simple differential recognition module and no interactive module has been developed for the people with DASH. The outcome of this study is a set of paper-based prototype interfaces for Smart Door Control to minimize number of steps involved in opening a door. The results of this study could serve as an initial guideline before designing an interface for people with DASH. Further work to extend this study is to design a usable interface that fit people with DASH of all ages using the head or other body segments such as done by Yoda et. al [6].

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