ABSTRACT

DEVELOPMENT OF A TOOLBOX FOR THE KINEMATIC EVALUATION OF HANDS-UP VIDEO GAMES

by
Brooke Marie Odle

Children with cerebral palsy (CP) often have limited upper extremity (UE) control. Virtual reality (VR) is a current technology being evaluated as a form of UE therapy for children with CP. The systems currently available have been developed with games that cannot be graded to match the skill level of children with severely impaired UE control. A novel video game platform, "Hands-Up", has been developed at New Jersey Institute of Technology. The platform features software that allows for the customization of games and encourages users to make purposeful UE movements. To quantify changes and improvement in movement due to increased game play, a MATLAB-based toolbox of functions was developed. The functions include measures of peak velocity, percentage time to peak velocity, number of movement units, and straightness ratio. Data collected during reaching tasks were analyzed to validate the toolbox. The toolbox of functions provides different ways to interpret user intent.

DEVELOPMENT OF A TOOLBOX FOR THE KINEMATIC EVALUATION OF HANDS-UP VIDEO GAMES

by
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INTRODUCTION

1.1 Background and Significance

1.1.1 Cerebral Palsy and Therapeutic Treatment for Children with Cerebral Palsy

Cerebral palsy refers to a group of nonprogressive, but often changing, motor impairment syndromes secondary to lesions or abnormalities of the brain arising in the early stages of its development (Wood, 2006). The causes of CP are unknown, but they have been attributed to injuries to the fetal brain before birth, premature birth, and injuries occurring shortly after birth. About half of the children diagnosed with CP have UE dysfunction, which makes activities involving reaching, grasping, and manipulation a challenge (Chen et al., 2007). Hands-Up is geared towards children with severely impaired UE control; and a target population includes children with spastic CP, as they have stiff muscles and the inability to relax them. When compared to their typically developing peers, children with spastic CP exhibit reaching patterns that are jerkier, slower, and less forceful (Chen et al., 2007).

Since reaching is involved in many activities of daily living, the focus of therapeutic treatment for children with spastic CP is to improve control of their UEs by practicing reaching movements. For the purposes of this study, reaching is defined as the voluntary positioning of the hand at or near a desired location so that it may interact with the environment (Chang et al., 2005). Practice, or repetition of movement, is a key feature of the motor skill learning therapeutic treatments given to children with spastic

CP because it helps with brain plasticity, or reorganization of the brain after learning a skill or suffering a lesion (Fetters and Kluzik, 1996). The therapeutic techniques used must be engaging and interesting to capture the child's interest, but at the same time, must be flexible enough to allow the child to make purposeful movements, and offer adequate feedback to the child concerning his or her performance. One of the current ways therapists are achieving this is through the use of VR therapy.

1.1.2 Virtual Reality (VR) Therapy

VR refers to the use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear to be and feel similar to real world objects and events. Users interact with displayed images, move and manipulate virtual objects, and perform other actions in a way that attempts to "immerse" them within the simulated environment and allow them to feel that they are within the virtual world (Weiss et al., 2004). Therapeutic treatment can be supplemented with VR because VR enables therapists to offer their patients individualized treatment, by adjusting their practice intensity, and positive visual and auditory feedback. VR also provides three-dimensional (3D) correspondence between the degree of movement in the real environment and the degree of movement observed on the computer screen (Chen et al., 2007).

One of the first studies to explore the effectiveness of VR therapy in improving UE function in children with spastic CP was Reid's (2002) pilot study with the IREX (formerly Vivid Group's Mandala Gesture Xtreme) system, a video-capture tool. Her subjects received an 8-week intervention of VR therapy with the system once a week for 90 minutes. Her study revealed that VR training with the IREX encouraged children to practice reaching movements, as the games allowed them to participate in new opportunities and increased their level of confidence (Reid, 2002). The screenshot of an IREX game in Figure 1.1 depicts the reaching movements that can be practiced, as the user reaches for the targets in the environment. VR is also attractive as a form of therapy because the improvements it causes in UE control may also cause changes in neuroplasticity of children with CP (You et al., 2005), (Fluet et al., submitted).

Figure 1.1 Screen shot of an IREX game that trains UE movements.

Source: http://www.gesturetekhealth.com/pdf/irex_side.pdf

As interest in VR training and interventions grew, researchers began to conduct more studies with commercially available systems, mainly the IREX and Sony PlayStation II EyeToy. Rand and colleagues conducted a study to determine the clinical usefulness of the EyeToy versus the IREX system (Rand et al., 2004). They were mainly interested in determining a cost-effective system that was engaging and could be used for rehabilitation in clinical settings. Since therapy does not end in the clinical setting, they were also looking for a system that could be used easily by patients in their homes. Rand and colleagues determined that the IREX was an unacceptable option because it was very expensive. The IREX system also required the use of a green screen because it was developed with "green-screen technology", and the immersive environments were projected onto that screen. They found the EyeToy to be a more viable option because it was more affordable and was easier to set up. The system was also engaging and their subjects seemed to enjoy their experiences with the EyeToy more than IREX (Rand et al., 2004). Because it was easier to set up, it was more ideal for the home setting. The EyeToy is a camera-based system that relies on user interaction. It does not use specific interfaces like the Nintendo Wii. It was designed for all, but researchers began applying it to UE therapy because the games could be used to train gross-motor UE movements. The movements made by the child in Figure 1.2 are examples of the type of UE movements encouraged by the EyeToy system's games.

Figure 1.2 Screen shot of an EyeToy game that trains gross-motor UE movements.

Source: http://wiki.groept.be/confluence/download/attachments/323/screenShot1.jpg

Although the EyeToy has several advantages, it has several disadvantages as well. One main disadvantage was its inability to grade the level of difficulty to meet the needs of patients with severe motor impairment. Another disadvantage was that it could not be used to train specific therapeutic goals (Rand et al., 2004), (Chen et al., 2007). The EyeToy games were created with three different speed settings: slow, medium, and fast. In a study concerning the effectiveness of VR interventions to improve UE control in children with CP, Chen and colleagues determined that the medium and fast speed settings were too fast for the children (Chen et al., 2007). Another limitation of the EyeToy is its inability to record sufficient data (Rand et al., 2004). For a system to be used for rehabilitation purposes in the clinical setting, therapists must be able to extract useful information that will enable them to monitor the progress of their patients.

There is a need for a VR gaming platform with features that are important in rehabilitation. Therefore, the most ideal VR rehabilitation training system is inexpensive and easy to set up, has graded levels of difficulty, can be used to train specific therapeutic goals, and can be customized to meet the individual needs of patients with limited motor impairment (Rand et al., 2004), (Chen et al., 2007). It should also incorporate the interaction principles featured in platforms like IREX and the EyeToy. Hands-Up incorporates all of these features; it is a video capture tool that is customizable to suit those various needs of children with UE impairment. For example, it provides for the range of flexion and extension necessary to address the issue of muscle contracture (Foulds et al., 2008).

1.1.3 NJIT "Hands-Up" Adaptable Video Game Platform

At the Rehabilitation Engineering Research Center (RERC) at New Jersey Institute of Technology (NJIT), an adaptable open-source gaming environment has been created for children with orthopedic disabilities. This unique environment allows them to play video games for therapeutic purposes and provides for customized speed and accuracy settings. The core of the gaming platform is a playing area created by graphical axes and game pieces represented by graphical patches which are programmed to interact with each other and the boundaries of the gaming environment. Behaviors include moving in a pattern, changing shape, color or size and even disappearing altogether, which are generally triggered by interaction with other pieces or the boundary of the environment (Irving and Odle, 2008).

The platform was created with MATLAB's Autonomous Robot toolbox and Simrobot (University of Brno, Czech Republic) and currently runs on the 2007b version of MATLAB (The MathWorks, Inc, Natick, MA). The platform also consists of a 30 frames per second webcam, which allows for external user input by taking snapshots to capture real-time hand movements (Irving and Odle, 2008), (Jensen and Foulds, 2007). The webcam currently being used is the Logitech Quickcam Pro 5000. A color detection scheme has been devised to use the photo information to locate the most probable position for one of three colored markers in the gaming environment: red, green, or blue (Irving and Odle, 2008). This is accomplished by capturing the real-time images of the picture at a 240 x 320 resolution and calculating the median of the center point of the red-green-blue pixel of the tracker in the player's hand. The user sees representations of his or her hands, allowing them to move and interact within the gaming environment (Jensen and Foulds, 2007).

The trackers can be implemented in a variety of ways. For example, a child can wear a colored sticker on his or her forehead or a piece of cloth wrapped around his or her hand, or hold an object that is one of the three colors: like a plastic utensil, a small soft handball, a marker, or a toy. Figure 1.3 depicts a child using a blue paper cup to play a Hands-Up game. This allows participation by all children regardless of range of motion, strength, and grasping ability (Irving, 2008). For example, a child with poor grasp control can still work on improving his or her UE range of motion by tying a colored cloth around his or her hand to play Hands-Up games. To prevent errors with detection, the color selected for the tracker should not be anywhere else in the player's environment. For example, if a player selects blue as the color marker and is seated in front of a blue wall, the software will recognize the wall (since it is larger and has more blue than the tracker used to play to the game) as the tracker; and since the wall is not going to move, the player will have a hard time playing the game.

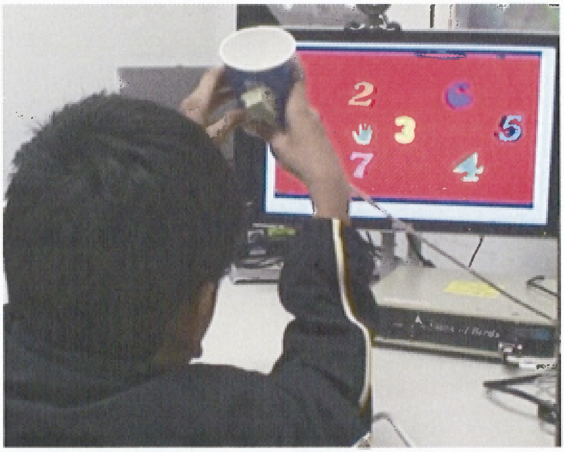


Figure 1.3 Screen shot of a Hands-Up game being played with a paper cup.

The various options for colored trackers are not the only adaptable feature of Hands-Up. The gaming environment is representative of the view of the camera, so there is much flexibility in the experience of the player (Irving, 2008). The orientation and position of the webcam is not limited; placing the webcam at a side view of the player or pointing down from above will require the user to move in a different plane. This is especially relevant to game design of someone with very limited mobility or someone who is restricted to a specific linear motion (Irving and Odle, 2008). Moreover, the closer a player is to the webcam, the less he or she will have to move To determine the best location for the webcam, before playing the game, the player has the opportunity to take a snapshot or himself or herself in his or her environment (Irving and Odle, 2008).

Also, each game features customizable speed and accuracy settings. The speed settings control how fast the game objects move on the computer screen. If the objects move slowly across the screen, playing the game becomes easier, while faster moving objects make the game more of a challenge. This feature is useful in a therapeutic setting because as a child becomes better at the game, the therapist can increase the speed to further challenge the patient to improve his or her reaching ability. The accuracy setting determines how close the hand has to be to an object to trigger a behavior (usually when the hand touches an object, the object will either follow the hand or the object will be deleted). The farther the hand has to be from the object, the easier the game becomes. The closer the hand has to be to the object, the more challenging the game becomes. This setting is also applicable for therapy because as the child improves in the game, the therapist can increase the setting to train the user to further improve his or her UE range of motion.

Although, Hands-Up has many customizable features, its initial two-dimensional environment did not have robust graphics comparable to those available in current VR-based gaming platforms. Currently, a 3D environment that supports stereo graphics has been in development. Whenever a game is created in the two-dimensional (2D) environment, Hands-Up has the ability to create a 3D version of that same game. The higher quality of graphics not only enhances the gaming experience for the player, but also helps the player recognize the objects easier.

1.2 Objective

Children with CP often have impaired UE control, which makes it more difficult for them to make purposeful reaching movements. They attend therapy sessions to practice making purposeful reaching movements. To make the therapeutic sessions more effective, therapists have considered the use of VR gaming platforms. Current commercial VR gaming platforms, like the Vivid GX IREX and Sony PlayStation II EyeToy, have several advantages, but have major disadvantages. IREX is too expensive to be used in clinical settings. The EyeToy lacks customization features, as its games cannot be graded to match the skill level of a user with UE impairment. It also cannot be used to train specific therapeutic goals. There is a limited number of publications addressing reaching and UE control in pediatric populations with CP; and each child with CP is different (i.e., cognitive ability, visual ability, hearing ability, level of motor function, etc). The Hands-Up adaptable video game platform was established with design principles for use with children with severe disabilities, like CP.

To understand the needs of children with CP, it was vital for Hands-Up to include as many customization options as possible. To gain an understanding of how the games should be customized, some therapists who treat children with severely impaired UEs were shown Hands-Up and its customization options. They found the platform to be promising and offered feedback on how the customization options could be enhanced for their patients. For example, some children may have impaired vision, so the objects appearing on the screen could be enlarged. Some children may have problems recognizing certain colors, so the colors used in most of the games were red, black, and white, because they allowed for a high contrast (K. Engel, personal communication, July 9, 2008). If children have impaired visual ability, they may rely more on auditory cues (L. Haug, personal communication, July 18, 2008). Therefore, auditory feedback in the form of sounds like hands clapping, crashing sounds, beeps, encouraging phrases, and songs, were incorporated throughout the game and once the game ended. The customization options available in Hands-Up allow the platform to be graded to meet the needs of children with severely impaired UE control. These options can be adjusted to train specific therapeutic goals.

In order to determine the clinical effectiveness of Hands-Up interventions, some type of outcome measures need to be assessed. Hands-Up has a few outcome measures that can be used to assess successful game play. Besides monitoring the adjustable speed and accuracy settings, the game duration can be tracked. Although these measures are useful, they have limited clinical effectiveness because no quantifiable data can be extracted from them. In order to determine the clinical effectiveness of a rehabilitation technique, one would want to use outcome measures correlated with a clinical assessment index. Since there are many types of clinical assessment indices available to therapists to assess the motor function of children with CP, each therapist uses a different index. However, these assessment indices may not always be used in the way they are intended, making the assessment index an inappropriate measure (Ketelaar et al., 1998). Some therapists have found that none of these assessment indices are sensitive enough to adequately assess the motor function of CP children with severe UE impairment and opt not to measure their patients with any clinical index (Fetters and Kluzik, 1996), (K. Engel, personal communication, July 9, 2008). In order to understand how children with UE impairment reach and to be able to track their improvement or changes in movement due to increased game play with Hands-Up, quantifiable measures are needed. If kinematic data were collected while children were playing games, an evaluation tool would be needed to quantify and evaluate the data. The objective of this study was to develop an evaluation tool based on kinematics for Hands-Up video games.

CHAPTER 2

EXPERIMENTAL DESIGN AND METHODOLOGY

2.1 Experimental Design of Reaching Task

The objective was to develop an evaluation tool for the analysis of Hands-Up video games. To accomplish this, a MATLAB-based toolbox of functions that allow for user defined analysis was devised. The functions were based on kinematic parameters commonly used in the literature to describe reaching and UE control. The kinematic parameters utilized are: movement time (MT), path length (PATH), peak velocity (PV), percentage time to peak velocity (PTPV), number of movement units (MU), average velocity (AV), movement onsets and offsets, range of motion (ROM), and straightness ratio (SR).

Once this toolbox of functions had been developed, it would have to be validated. Validation of the toolbox was achieved by evaluating the toolbox with data collected during a reaching task. The data were collected at 100 frames per second with a Flock of Birds (FOB) (Ascension Technologies) electromagnetic position sensor.

The reaching task, depicted in Figure 2.1, involved holding the FOB sensor in one hand in 3D space, while reaching to three stickers on a sheet of paper. The stickers were 12 inches apart, forming the shape of a triangle. One participant performed the task twice: fast and accurately and fast and less accurately. The participant began each trial at the lower left hand corner (purple sticker), reached towards the apex (green sticker), towards the lower right hand corner (orange sticker) and then back to the lower left hand corner. It is important to note that any type of reaching task could have been used for the development of the toolbox. This particular task was selected because it was a simulation of a game being played in the horizontal plane.

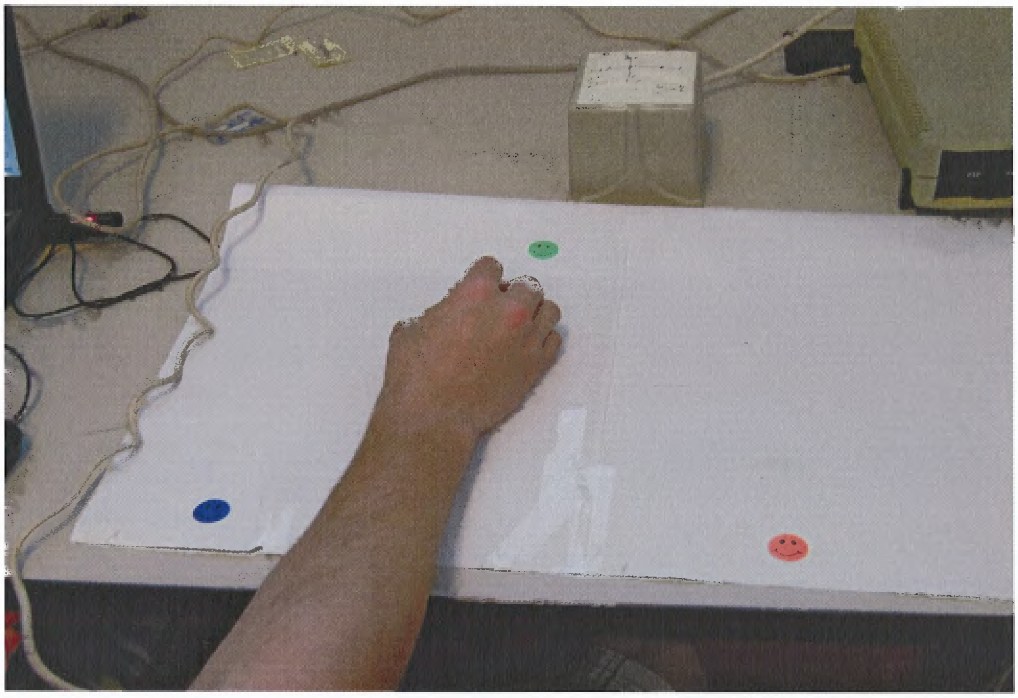


Figure 2.1 Set-up of Reaching Task.

2.2 Toolbox of Kinematic Functions

The toolbox developed consists of 14 different functions, which are listed in Table 2.1. It includes the filter function (BMOFILTR) used to process the data and a peak detection function (PEAKDET, written by Eli Billauer) to find the local maxima and minima in the tangential velocity profile. The functions are utilized by "calling" them in MATLAB scripts or directly from the command window. Instead of having to write one script with all of the functions, the toolbox option allows one to collect the functions and store them together in a saved "path" in MATLAB, so that they can be readily called.

Table 2.1 List of Toolbox Functions and their Purpose

	Data Processing
bmofiltr	Filters raw data
	Velocity-Based
movtim	Computes movement time
tangvel	Computes tangential velocity and plots profile
ptv	Computes peak tangential velocity
ptpv	Computes percentage time to peak velocity
avgvel	Computes average velocity
	Movements and Holds
monoff	Plots identified movement onsets and offsets on tangential velocity profile
	Smoothness
peakdet	Detects peaks in velocity profile
mu	Identifies movement units and counts total number of movement units
	Straightness
cdist	Computes cumulative distance traveled
straightness	Computes straightness ratio
dt	Computes straight-line distance from movement onset to movement offset
pathlen	Computes path length
	Range of Motion
posrange	Computes range of motion for x,y, and z planar directions

2.2.1 Brief Description of Toolbox Functions

The function BMOFILTR is a Butterworth filter for raw data. An example of how this function can be called is: y = bmofiltr(o,s,f,x), where o, s, f, and x are input arguments for order, sampling rate, cut-off frequency, and raw data, respectively. The function is both a low-pass filter, so no frequencies above the cut-off frequency are processed. The function is also a zero-lag filter that filters the data at a specified order. It can receive raw data of any length that has been sampled at a specified sampling rate. The variable returned (y) is a vector of the filtered data. For this study, the position data that were collected and filtered are reported in centimeters (cm).

The function MOVTIM computes movement time of the reach. An example of how this function can be called is: mt = movtim(y,s), where y is the filtered data and s is the sampling rate. The variable returned (mt) is the movement time and it is computed in seconds.

TANGVEL is a function that computes the tangential velocity of 3D position data of any length as well as generates a plot of the velocity profile. An example of how this function can be implemented is: [t,v] = tangvel(X,Y,Z,T), where X, Y, and Z are the x, y, and z coordinates of the position data and T is the time of the movement duration. The output variables returned are t and v, where t is a time vector (from 0 to the length of the data) and v is a vector that contains the tangential velocity values.

PTV is a function that computes the maximum peak velocity of the tangential velocity profile. An example of how this function can be called is: pv = ptv(v), where input argument v is the tangential velocity vector. The output variable (pv) is the peak velocity.

PTPV is a function that computes the percentage time to peak velocity. An example of how it can be called is: perctpv = PTPV(pv,v,t,mt), where pv is the peak velocity computed by the PTV function, v is the velocity vector, t time the time vector, and mt is the value for movement time computed by the function MOVTIM. The variable returned is perctpv, which is the time to peak velocity, expressed as a percentage.

AVGVEL is a function that computes the average velocity of the movement. An example of how this function can be used is: av = avgvel(v). In this case, v is the input argument for the velocity vector. The variable returned is av, which is the average velocity.

In its initial state, MONOFF is more of a script than a function. The user enters the values identified as movement onsets and offsets into arrays (mon for movement onset and mof for movement offset). Once the arrays are established, the tangential velocity profiles is plotted and magenta asterisks are placed at the sample numbers that correspond to the movement onsets, while cyan asterisks are placed at the sample numbers that correspond to the movement offsets. As the method for detecting movement onsets and offsets becomes more automated, monoff will be converted to a true function.

PEAKDET is a function that detects the peaks in a vector of data and was written by Eli Billauer. For the purposes of this toolbox, the function has been used to identify the local minima and maxima of the tangential velocity profile. It is used in conjunction with the function MU, which detects and reports the number of movement units in a reach. Within the MU function, PEAKDET is called as follows:

[maxtab,mintab] = peakdet(v,th). The input arguments are v, the tangential velocity vector, and th, the peak threshold. This threshold value represents the minimum distance between a peak and its surrounding, in order for a peak to be considered a peak. The local minima are found in the same manner. Maxtab and mintab are the variables returned to the MU function script and they are the vectors that contain the peak or valley value and its sample value within the tangential velocity profile. The tangential velocity plot is generated with a green asterisk placed at each detected local minimum and a red asterisk placed at each detected local maximum. The function MU may be called as follows: [maxtab,mintab, nummu] = MU(v,t). The input variables v and t are the input variables passed to the PEAKDET function. The function MU not only returns the maxtab and mintab vectors determined by the PEAKDET function, but also returns the variable nummu, which is the total number of movement units made in the reach.

CDIST is a function that computes the cumulative distance traveled during the reach. An example of how this function can be called is: cd = cdist(X,Y,Z,v,t). The input arguments X, Y, and Z represent the vectors containing the filtered X, Y, and Z position data. The velocity vector is represented by the variable v and t represents the time vector. The variable returned (cd) is a vector of the cumulative distance traveled. This function is used in conjunction with the straightness ratio function STRAIGHTNESS.

DISTTRAV is a function that computes the straight-line distance between the movement onset and the movement offset. The function can be called as follows:
dt = disttrav(X,Y,Z), where the input arguments X, Y, and Z are the vectors containing the filtered positions of the x, y, and z data. The distance formula is used to compute the

distance traveled and returns a single variable (d) to represent the straight-line distance. It is also used in conjunction with STRAIGHTNESS.

STRAIGHTNESS is a function that computes the straightness ratio of the reach. The function can be called as follows: sr = straightness(X,Y,Z,cd,dt). The input arguments X, Y, and Z are the vectors containing the filtered positions of the x, y, and z data. Input argument cd is the cumulative distance vector. Input argument dt is the straight-line distance traveled from the movement onset to the movement offset. SR is the variable returned and it is the straightness ratio. In addition to computing the straightness ratio, the function also generates a plot of the user's trajectory with a plot of a line between the x, y, and z position movement onset and offset values.

POSRANGE is a function that finds the range of motion of the x, y, and z position data during the reach. The function can be called as follows: [x_rom,y_rom,z_rom] = posrange(X,Y,Z). The input arguments X, Y, and Z are the vectors containing the filtered positions of the x, y, and z data. The variables returned are x_rom, y_rom, and z_rom, which are the range of motion values for each planar direction. The function also generates a plot of the x, y, and z trajectories.

2.2.2 Toolbox Functions and their Relationship to Reaching

Of the 14 functions, four are closely related to velocity. They are MOVTIM (movement time), PV (peak velocity), PTPV (percentage time to peak velocity), and AV (average velocity). Movement time (MT) is the total time needed from the start of the reaching movement until a target is acquired. It can be used to quantify the speed of the reaching movement (Chang et al., 2005). MT will be reported in seconds (s). Peak velocity is the maximum velocity of the reaching movement. Both PV and AV will be reported in centimeters/second (cm/s). The percentage time to peak velocity (PTPV) is the percentage of total time of a reach where the PV occurs. This value can be used to describe the control strategy of reaching (Chang et al., 2005). A typical reach made by an adult with no neurological impairment results in a bell-shaped tangential velocity with a single peak and the PV will occur about halfway through the reach, so the PTPV is about 50% (Morasso, 1981). A PTPV greater than or less than 50% represents deviation from the typical reach and is represented by skewing of the bell-shape in the velocity profile. PTPV will be reported as a percentage (%).

Reaching patterns can be described as a series of movements and holds (Liddell, 1984). To ensure that only pure movement is being assessed by the toolbox functions, the reaching patterns had to be separated into movements and holds by determining movement onsets and movement offsets in the velocity profile. A movement onset is considered the beginning of the movement, while the movement offset indicates when a movement has ended. Holds are the area of the velocity profile between the offset of one movement and the onset of the next movement. Movement onsets and offsets were determined based on a method described by Adamovich (S. Adamovich, personal communication, May 6, 2009). First, the PVs were detected. For the PV of each reach, 10% of the PV was found on either side of the velocity curve. A statistical analysis was conducted on the noise, or area between one reach and the next. The mean, standard deviation, and 1.5 times the standard deviation were computed. The movement onset was designated as the first value in that region that exceeded 1.5 times the standard deviation, while the movement offset was designated as the first value in that region that was less than 1.5 times the standard deviation. There are many different techniques used to determine movement onsets and offsets, so the values selected (10% and 1.5 times standard deviation) are subjective. The percentage of the PV and the factor multiplied by the standard deviation can be selected by the user. Future versions of the toolbox will consist of several different methods used in the literature to determine movement onsets and offsets, so the user can select the technique of his or her choice.

Movement units (MUs) are considered corrections in the trajectory or the stop-stop or jerkiness of a reach; and they describe the smoothness of a reach (Fetters and Kluzik, 1996), (Chang et al., 2005), (Chen et al., 2007), (Thelen et al., 1996). The more MUs present in the reach, the more corrections made in the reach and the less smooth the movement is. Just as there are many different techniques used to determine movement onsets and offsets, there are different techniques for determining movement units. The technique used in the toolbox is that of Thelen and colleagues, where a movement unit is defined as a speed maximum between two minima, where the difference between the maximum speed and both minima exceeded 1 cm/s (Thelen et al., 1996). In order for the number of MUs to be determined, the peaks had to be detected in the tangential velocity profile first.

The toolbox contains two functions that measure straightness: path length (PATH) and straightness ratio (SR). PATH or hand path is the total distance traveled from the start of the reach to the end of the reach. When the starting position is fixed, PATH can be used to describe the straightness of the reaching trajectory (Chen et al., 2007), (Fetters and Kluzik, 1996). PATH will be reported in cm. SR is the ratio of the PATH to the straight line distance between the movement onsets and offsets of the reach (McCombe

Waller et al., 2008). The closer the ratio is to 1, the straighter the reach. If the ratio exceeds 1, curvature is present in the reaching trajectory.

The range of motion (ROM) represents the range in distance the participant traveled in the X, Y, and Z planar directions. ROM will be reported in cm as well. This is an important function to include in the analysis of Hands-Up games because children with UE impairment may make more movements in the non-planar direction to compensate for the severity of their impairment. In terms of the reaching task, the participant had no UE impairment, so compensation was not a concern. However, it was still useful to determine the ROM in the reaching task for the non-planar direction. The participant held the sensor in the air while reaching to the different targets, as opposed to moving the sensor along the sheet of paper. Determining the ROM in the Z axis verified that the participant was holding the sensor above the sheet of paper while reaching. Noting the ROM in the planar directions is important because it can be used to track the progress of a child with UE impairment. Since children with UE impairment have a limited ROM, if they are able to increase their ROM in the planar directions, it may be indicative of them improving their UE control. In terms of the reaching task and Hands-Up games, determining the ROM of the planar directions can be useful to understand the control strategy of the participant. If the ROM increases from one trial to the next, it may be evidence of the participant overshooting the reach and lack of accuracy in acquiring a target.

2.3 Data Analysis

Once the 3D data were collected, they were filtered with a zero-lag Butterworth filter. From the filtered data, the kinematic outcome measures were computed. These measures were mainly derived from the trajectory and the tangential velocity profile. To assess the sensitivity of the toolbox functions, several functions were selected to determine the intent of the participant. These parameters were PV, AV, number of MUs, designation of movement onsets and offsets, and duration of holds.

While determining PVs, the shape of the PVs was noted as well. The tangential velocity profile of the entire trial was viewed to determine if there were symmetric bell-shaped profiles or deviations from the bell-shape, as described by Morasso (Morasso, 1981).

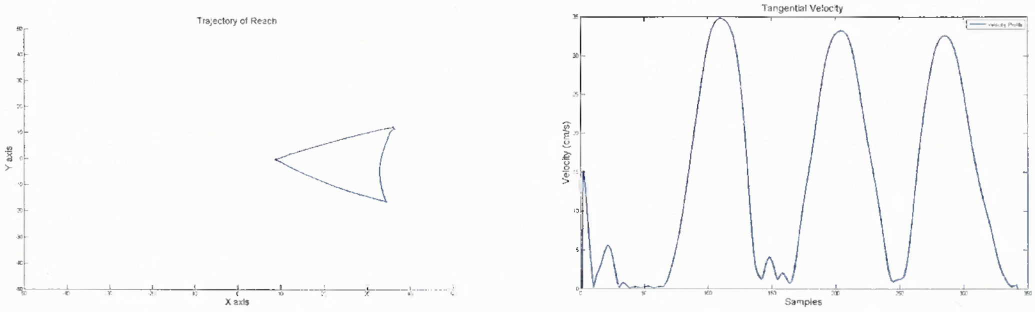
Designating movement onsets and offsets from movements and holds is vital because the positions of the targets in the task were unknown. Since the analysis had to be based on pure movement, the identification of movements and holds was needed. This would help distinguish when the participant was moving and when the participant had acquired the target (hold). This is also important for Hands-Up because the targets in the games are on the screen, while the reaching movements made to acquire those targets are made in 3D space. This is most appropriate for children with CP because of the limitations presented by their UE impairment. This concept in Hands-Up is unlike Fitt's Law, where contact with a target is required. Determining the movement onsets and offsets in the entire trial allowed the function to serve as a measure of variability, reporting the number of times the participant exceeded rest.

CHAPTER 3

RESULTS

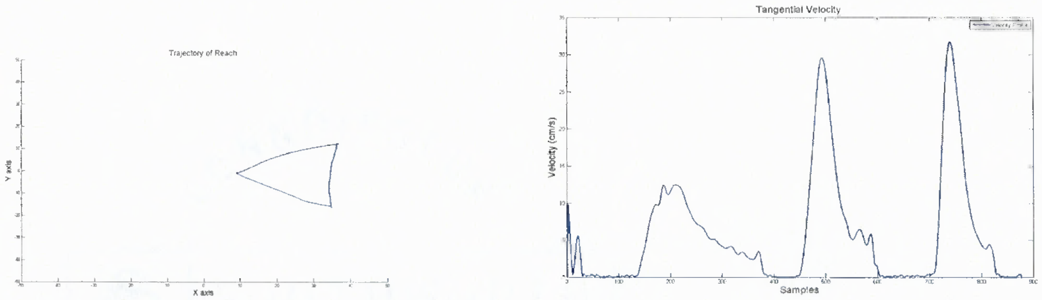
3.1 Assessment of User Intent during Reaching Tasks

It was known that the two trials collected were different types of reaching patterns; however, the participant did not tell the experimenter what types of reaching were made so that the toolbox could be used to assess the intent of the participant and distinguish the types of reaching patterns made. Figures 3.1a and 3.1b represent Trial 1, while Figures 3.2a and 3.2b represent Trial 2. When looking at the trajectory of the reaching trials (Figures 3.1a and 3.2a), they seem very similar.



(a) (b)

Figure 3.1 Trial 1 of Reaching Task: Trajectory (a), Tangential velocity profile (b).



(a) (b)

Figure 3.2 Trial 2 of Reaching Task: Trajectory (a), Tangential velocity profile (b).

However, when viewing the tangential velocity profiles of the two trials (Figures 3.1b and 3.2b), the differences in the trials can be noted. The tangential velocity profile of Trial 1 features three peaks in the velocity profile, representing the three directional reaches involved in the task. The velocity profile features bell-shaped velocities, typical of standard reaching, and appear to have similar PVs. Three peaks in velocity, representing the three directional reaches, are also seen in Trial 2. The velocity profiles of Trial 2 are not consistent, unlike those of Trial 1. Deviations from the bell-shaped velocity profile are also seen. The PVs of reaches 2 and 3 are quite similar, while the PV of reach 1 is much lower. Also, there are several peaks in the velocity profiles, suggesting that more movement units may be found in Trial 2 because the peak velocity occurs early and corrections were made as the participant slowed down to acquire the target. This analysis suggests that Trial 1 consisted of fast and accurate reaching, while Trial 2 consisted of fast and less accurate reaching. Changes in movement can be detected with these functions, however the results are not quantifiable and further analysis is needed.

3.1.1 Identification of Peaks

For an additional analysis, the peaks in the velocity profile were detected so that the number of MUs could be determined for each trial. First, the function PEAKDET was used to find the local maxima and minima of the velocity profile. Then, the function MU was used to detect the movement units and compute the total number of movement units in the trial.

The local maxima and minima detected in the tangential velocity profile of Trial 1 are depicted in Figure 3.3. The function MU determined that there were 5 MUs in the reach. There was 1 local minimum between reaches 2 and 3 and the velocity slows down close to zero and it appears to be a hold. Between reaches 1 and 2, there are two smaller peaks, making it more difficult to determine where the hand came to rest. It is difficult to distinguish noise, holds, and movements.

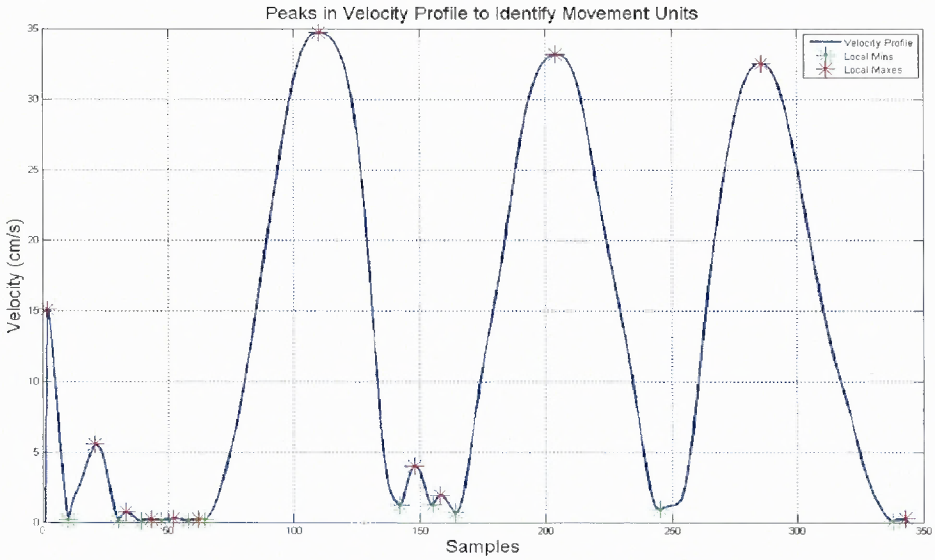


Figure 3.3 Peaks detected for reaching movements made during Trial 1.

The local maxima and minima detected in the tangential velocity profile of Trial 2 are depicted in Figure 3.4. There are several local maxima and minima detected with the PV for each reach. When looking at the tangential velocity profile, it was determined that the inconsistent skewing seen in tangential velocity profile could be interpreted as the PV occurring early and the participant had to slow down to acquire the target, meaning that multiple MUs would be detected. This interpretation is verified, as there is one PV with several maxima and minima detected following it. The function MU determined that there were 8 MUs in the reach. Unlike the velocity profile of Trial 1, the velocity profile of Trial 2 features many peaks as the velocity approaches zero between each reach. Since velocity approaches zero and remains there, it can be determined that the areas between the reaches feature holds. Since the holds appear longer than those of Trial 1, it is not clear if the target was acquired and the participant waited before reaching for the next target (indicative of some type of movement planning) or if some movement was being made since there were several local maxima and minima detected in those regions.

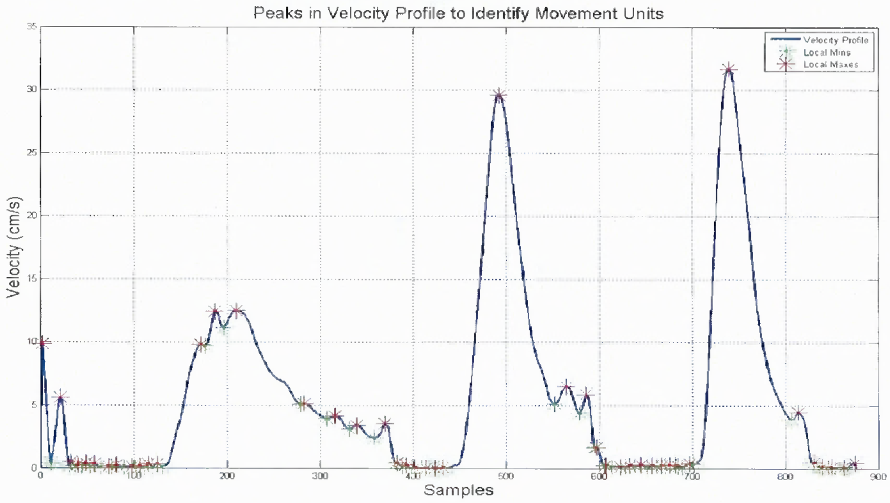


Figure 3.4 Peaks detected for reaching movements made during Trial 2.

This analysis validated interpretations made based on the first analysis, but there were still questions that remained for each trial. The second analysis still did not yield any quantifiable results, so an additional analysis was needed. This analysis would entail designating the movement onsets and offsets for each reach in each trial. Once the movement onsets and offsets were designated, additional toolbox functions would be used to determine what happens during movements and holds.

3.1.2 Movements and Holds

As mentioned earlier, Liddell's concept of movements and holds was being applied to understand reaching movements. Liddell originally used the concept in describing American Sign Language. This concept led to the designation of movement onsets and offsets for this study.

The movement onsets and offsets were determined by using the previously described method. The movement onsets and offsets designated in Trial 1 are depicted in Figure 3.5. This method revealed that the two peaks between reach 1 and 2 belonged to reach 2. The hold between reach 1 and reach 2 lasted for 0.01 seconds, while the hold between reach 2 and 3 lasted for 0.04 seconds. Since the duration of holds were so small, it could be interpreted that the movements made were continuous because the velocity did not approach zero, although it did decrease.

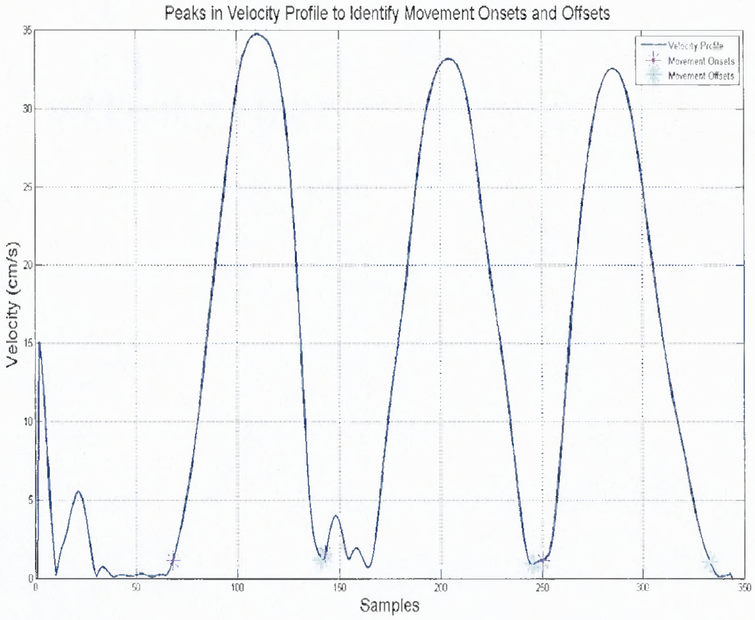


Figure 3.5 Movement onsets and offsets designated in Trial 1.

The movement onsets and offsets designated in Trial 2 are depicted in Figure 3.6. This method revealed that the areas of zero velocity were pure holds. The duration of the hold between reach 1 and 2 was 0.66 seconds, while the duration of the hold between reach 2 and 3 was 1.06 seconds.

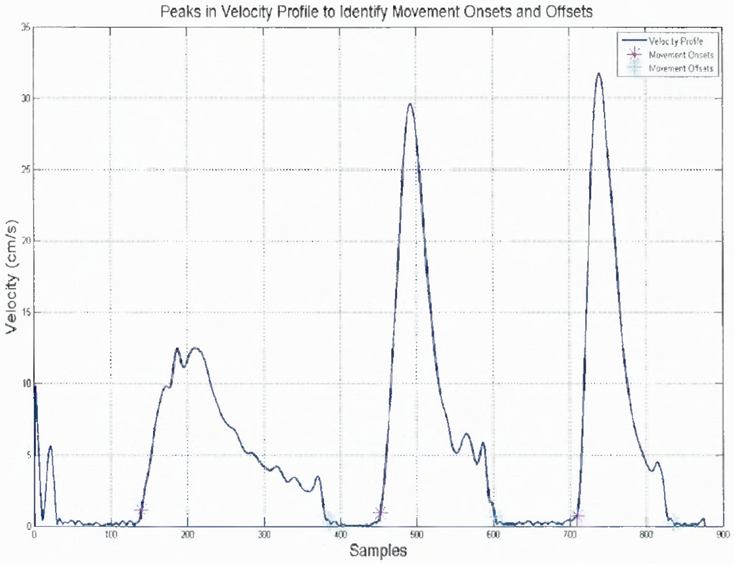


Figure 3.6 Movement onsets and offsets designated in Trial 2.

Once the movement onsets and offsets were designated, it was understood that the movements (reaches) were separated from the holds, allowing for an analysis of pure movement. To understand what occurs during movements, several toolbox functions were used to quantify the reaches. For the reaches in Trial 1, the toolbox functions were used to assess whether the consistency in the reaches changed over time. For the reaches in Trial 2, the toolbox functions were used to assess the inconsistency in the velocity profile.

3.1.3 Use of Toolbox Functions to Further Quantify Reaching

Four different types of parameters were used to quantify the reaches in both trials. The first types of parameters utilized were the velocity based parameters: MT, PTPV, and AV. The second types of parameters utilized were the straightness parameters: PATH and SR. The third parameter utilized was the smoothness parameter, number of MUs. The fourth type of parameter utilized was the range of motion function (POSRANGE). The ROM was determined for each planar direction, even though the reaches were made in the X-Y plane. The results of the analysis for both trials are listed in Table 3.1.

Although the reaches made in Trial 1 were very consistent, there were some slight differences in the analysis results. For example, the MTs were different for each reach; and 2 MUs were made during reach 2, while 1 was made during reaches 1 and 3. The PV for reach 3 occurred earlier than the PVs for reaches 1 and 2. The PATHs for reaches 1 and 3 were very close in length, while the PATH generated during reach 2 was slightly larger. The ROM in the X and Z planar directions were very similar for reaches 1 and 2, while the ROM in the Y direction was slightly larger during reach 2. The ROMs for reach 3 vary from the previous reaches, but that was the reach from the right corner of the triangle to the left corner of the triangle, which predominantly involved reaching in the Y-direction of the X-Y plane. The results verify this, as most of the movement was in the Y direction, with limited movement in the X and Z directions. However, the PVs and SR are fairly consistent. Although the three reaches in Trial 1 appeared very similar, there were slight differences in the reaches as they were made over time and the selected toolbox functions were sensitive enough to detect those changes.

Even though inconsistencies in the reaches made during Trial 2 were noted, reaches 2 and 3 appeared very similar and those similarities were detected in the reported values. The PVs, AVs, and PATHs were very close for both reaches. Even though the reaches appeared inconsistent, there were some similarities between reaches 1 and 2. For example, the number of MUs was the same for both reaches and the PTPVs were very close for both reaches. Moreover, the MTs vary for all three reaches, indicating the inconsistency in the reaches.

Table 3.1 Parameter-based analysis of Trials 1 and 2

	Trial 1			**Trial 2**		
	Reach 1	**Reach 2**	**Reach 3**	**Reach 1**	**Reach 2**	**Reach 3**
MT (s)	0.74	1.03	0.84	2.46	1.51	1.27
PV (cm/s)	34.4	32.9	32.2	12.4	29.4	31.5
PTPV (%)	57.5	59.8	43.4	28.6	27.3	24.6
AV (cm/s)	19.9	15.4	17.3	6.32	11.5	12.2
SR	1.01	1.05	1.04	1.04	1.16	1.08
PATH (cm)	29.9	32	29.5	31.2	35.1	31.1
MU	1	2	1	3	3	1
XROM (cm)	27	26	3.4	27	26	2.5
YROM (cm)	12	17	28	13	16	29
ZROM (cm)	3.1	3.6	1.7	4.6	8.5	3.6

CHAPTER 4

DISCUSSION

4.1 Three-Dimensional Analysis of Reaching Task

4.1.1 Analysis of Trial 1

The analysis of Trial 1 demonstrated that the toolbox functions were sensitive enough to detect and assess changes over time in reaching movements that appear to be consistent. Although the reaches appeared similar, there were slight variations in some of the reported parameters, including MT, number of MUs, and PTPV. The MT was the longest for reach 2 because the two small peaks were considered part of the reach, increasing the time needed to acquire the target. There was an additional number of MUs made during reach 2 as well because those two peaks were designated as the beginning of reach 2 and the first peak contained a MU. Even though the two small peaks were designated as the beginning of reach 2, the PTPV for reach 1 and reach 2 were very similar.

4.1.2 Analysis of Trial 2

The inconsistencies in the reaches made during Trial 2 could easily be seen in the tangential velocity profile, however, the analysis with the toolbox functions were sensitive enough to detect and assess the inconsistencies so that they could be quantified. One inconsistency that was detected and assessed was that although the PV and AV for reach 1 was much less than those of reaches 2 and 3, reach 1 had a SR value that indicated that it was the straightest reach. Also, the number of MUs was the same for reaches 1 and 2, while the number of MUs generated during reach 3 was less than that of both reaches. Thelen and colleagues noted that even though MU and straightness are related, they are not the same. This was because a slower movement with more corrections may be straighter than a movement generated with large and fast MUs (Thelen et al., 1996).

It was already mentioned that the number of MUs was the same for reaches 1 and 2, but the MT was longer during reach 1, while the PATH was greater during reach 2. This finding for reach 1 was interpreted as: more corrections were needed for slower movements and as the corrections were being made, more time was needed to acquire the target. This finding for reach 2 was interpreted as: since the PV occurred early in the reach, the participant had to slow down after achieving the PV to acquire the target. In doing this, more corrections needed to be made to approach the target.

It was also noted that even though the PATHs were similar for reaches 1 and 3, they differed in the number of MUs made. The interpretation of this finding was: since the PV was greater and the MT was less in reach 3 than in reach 1, the faster movement was generated quicker with fewer corrections.

4.2 Two-Dimensional Analysis of Reaching Task

For the purposes of the reaching task, FOB was used as a "gold standard" for data collection. FOB is expensive, so it may be impractical to collect data with it in a clinical setting as Hands-Up games are played. One of the criticisms of the EyeToy was that it could not record sufficient data. It would be ideal if the web cam used with Hands-Up could be used for data collection because less equipment would be needed. This led to determining whether the web cam used with Hands-Up could be used to record data. If the web cam were to be used for data collection, the data collected would only be two-dimensional. It was unknown if the 2D data could be used with the toolbox functions to describe reaching in the same manner as the 3D data. At the time of testing, 2D data from the web cam of the participant engaging in the reaching task could not be collected. As an alternative, 2D data from the two reaching trials were replicated from the 3D data. In order to do this, the Z axis was held constant, so the analysis could be based on the X and Y axes. If the 2D data yielded results that were similar to the 3D analysis, the web cam may be a viable tool for data collection. Once the data was generated in 2D, the same analyses of detecting the peaks and distinguishing movements from holds were conducted for both trials as well. The toolbox functions were also used to quantify the consistencies and inconsistencies in the movements.

4.2.1 Identification of Peaks

The local maxima and minima of the 2D tangential velocity profile of Trial 1 were identified by the function PEAKDET and are depicted in Figure 4.1. The same three peaks in the profile were seen, as in the 3D analysis. The consistent bell-shaped curves also remained in the 2D analysis. It was apparent that the 2D tangential velocity profile was similar to that of the 3D analysis. The function MU detected a total of 4 MUs in the entire trial. The number of MUs detected in the 2D data was one less than the total number of MUs detected in the 3D analysis of the trial data. Unlike the 3D analysis, there were 2 local minima and 1 local maxima detected between reaches 2 and 3, but the velocity still slowed down close to zero. In the 3D analysis, that region appeared to be a pure hold. In the 2D analysis, it appeared to be a movement and a hold. The two smaller peaks were still detected between reaches 1 and 2; and it was still difficult to determine where the hand came to rest. The movement onsets and offsets needed to be designated to determine whether the region between reaches 2 and 3 was a pure hold or contained some movement and a hold. The movement onsets and offsets will need to be designated to determine if the 2D analysis finds the same onset and offset points on the curve as the 3D analysis, or if those points have shifted.

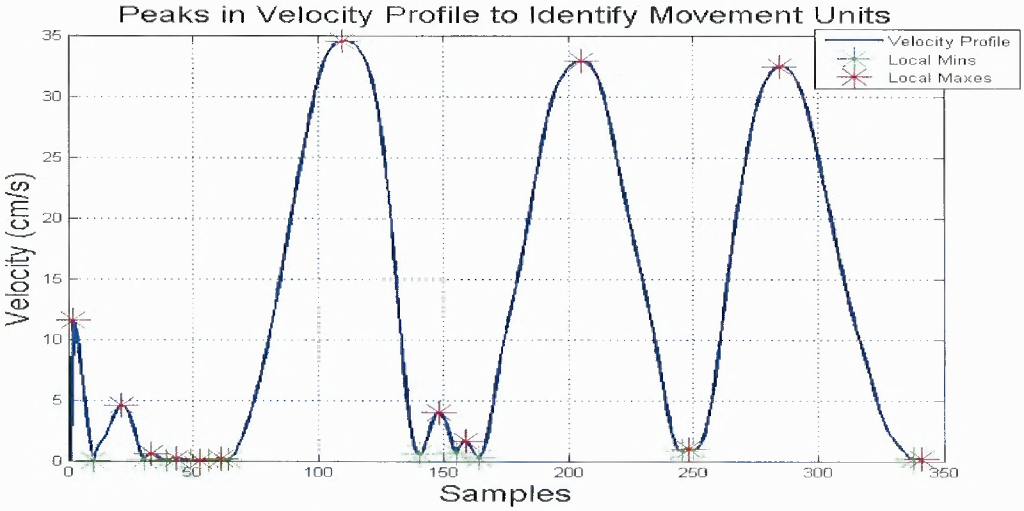


Figure 4.1 Peaks detected for reaching movements made during Trial 1 (2D).

The local maxima and minima detected in the tangential velocity profile of Trial 2 are depicted in Figure 4.2. Several local maxima and minima were detected with the PV for each reach, as in the 3D analysis. The same inconsistent skewing was seen in the tangential velocity profile and was still interpreted as: the PV occurred early, so the participant had to slow down to acquire the target, meaning that multiple MUs would be detected. This interpretation was verified, as there was one PV and several maxima and minima detected following the PV, as seen in the 3D analysis. The function MU determined that there were 7 MUs in the reach, which was also one less MU detected than in the 3D analysis. The velocity profile of Trial 2 still featured many peaks as the velocity approached zero between each reach. Since the velocity approached zero and remained there, it could still be determined that the areas between the reaches featured holds. The movement onsets and offsets will need to be designated to determine if the 2D analysis finds the same onset and offset points on the curve as the 3D analysis, or if those points have shifted.

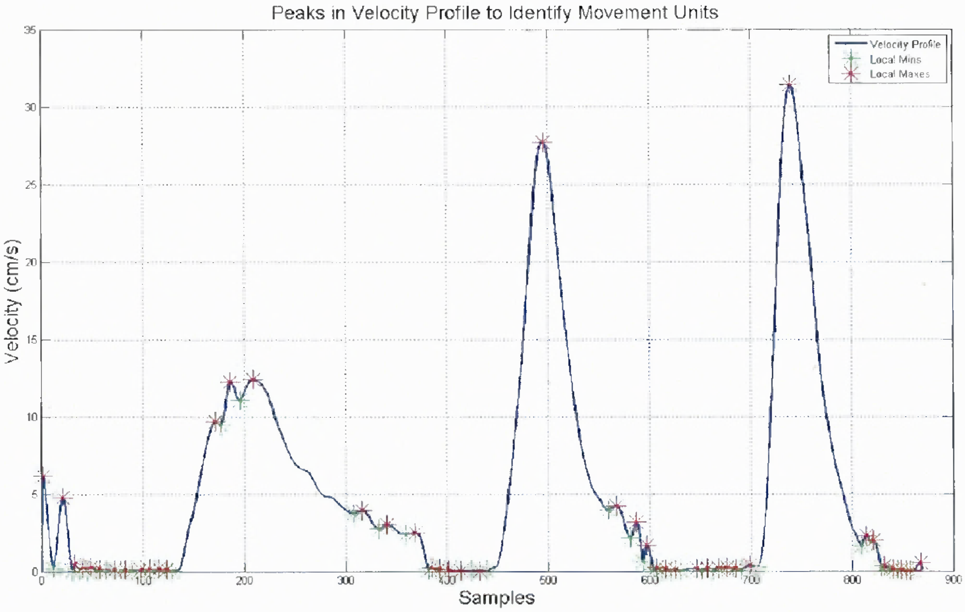


Figure 4.2 Peaks detected for reaching movements made during Trial 2 (2D).

4.2.2 Movements and Holds

The movement onsets and offsets designated in the 2D analysis are depicted in Figure 4.3. The method used to determine movement onsets and offsets still revealed that the two peaks between reach 1 and 2 belonged to reach 2, however the movement onset of reach 2 occurred later in the first peak. The movement offset of reach 2 and the movement onset of reach 3 occur around the same points where the local minima were detected in the tangential velocity profile. The hold between reach 1 and reach 2 lasted for 0.08 seconds, while the hold between reach 2 and 3 lasted for 0.07 seconds. The duration of the holds in the 2D analysis is longer than that of the 3D analysis, but those durations were still so small that the reaching movements could be interpreted as continuous movements. Because the durations were slightly longer, the movement onsets and offsets slightly differed from those in the 3D analysis.

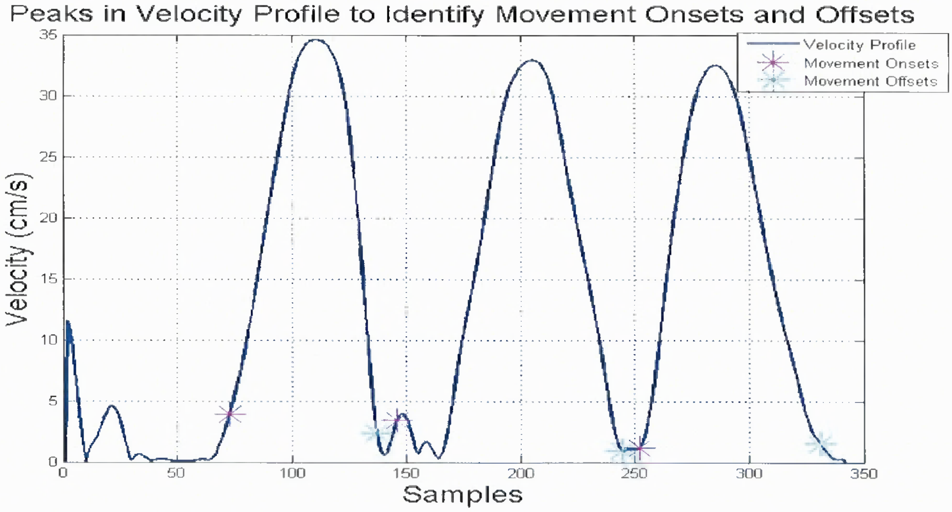


Figure 4.3 Movement onsets and offsets designated in Trial 1 (2D).

The movement onsets and offsets designated in Trial 2 are depicted in Figure 4.4. This method used to designate movement onsets and offsets also revealed that the areas of zero velocity were pure holds, as determined in the 3D analysis. The duration of the hold between reach 1 and 2 was 0.68 seconds, while the duration of the hold between reach 2 and 3 was 1 second. The hold durations were very consistent with the 3D analysis.

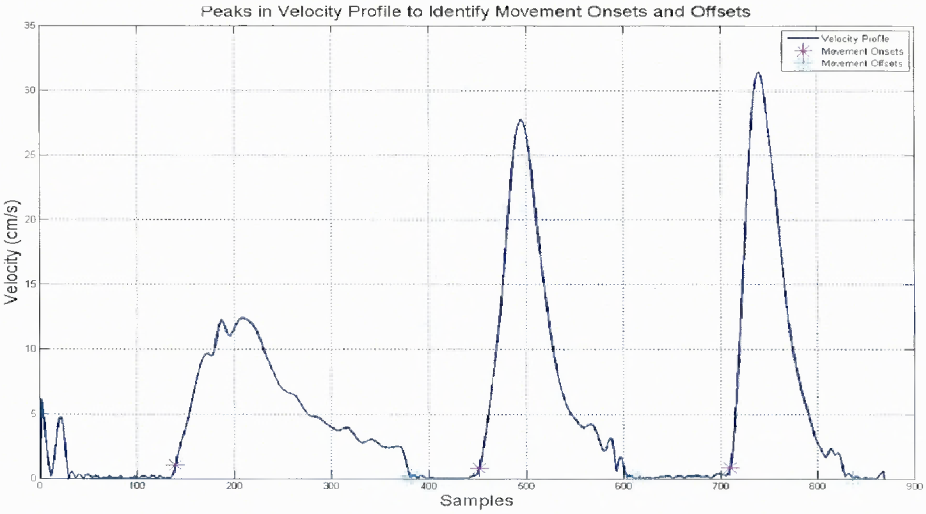


Figure 4.4 Movement onsets and offsets designated in Trial 2 (2D).

To determine if the parameters used to quantify the data in the 3D analysis will yield similar results for the 2D analysis, the same toolbox functions were used to assess and detect changes in the reaches for both trials.

4.2.3 Use of Toolbox Functions to Further Quantify Reaching

The results of the 2D analysis of Trial 1 are listed in Table 4.1 and they were compared with the values reported from the 3D analysis. The 2D analysis demonstrated consistency in the reaches in terms of SR and number of MUs detected. The PVs and PATHs were also similar. There were differences in the MT, PTPV, and AV values. Comparing the 2D analysis to the 3D, the results were very similar, especially the XROM and YROM values.

Table 4.1 Three-Dimensional versus Two-Dimensional Analysis of Trial 1

	Trial 1: 3D			**Trial 1: 2D**		
	Reach 1	**Reach 2**	**Reach 3**	**Reach 1**	**Reach 2**	**Reach 3**
MT (s)	0.74	1.03	0.84	0.65	0.99	0.80
PV (cm/s)	34.4	32.9	32.2	34.2	32.7	32.1
PTPV (%)	57.5	59.8	43.4	57.8	60.2	41.8
AV (cm/s)	19.9	15.4	17.3	22.2	15.7	17.9
SR	1.01	1.05	1.04	1	1.03	1.02
PATH (cm)	29.9	32	29.5	29.3	31.4	29
MU	1	2	1	1	1	1
XROM (cm)	27	26	3.4	27	26	3.4
YROM (cm)	12	17	28	12	16	28

The results of the 2D analysis of Trial 2 are listed in Table 4.2 and they were compared with the values reported from the 3D analysis. The 2D analysis demonstrated the inconsistency of the three reaches in terms of MT, PV, AV and number of MUs detected. However, there was some consistency among the SR and PATH values. When comparing the 2D analysis to the 3D analysis, the results were very similar.

Table 4.2 Three-Dimensional versus Two-Dimensional Analysis of Trial 2

	Trial 2: 3D			**Trial 2: 2D**		
	Reach 1	**Reach 2**	**Reach 3**	**Reach 1**	**Reach 2**	**Reach 3**
MT (s)	2.46	1.51	1.27	2.44	1.58	1.28
PV (cm/s)	12.4	29.4	31.5	12.4	27.6	31.2
PTPV (%)	28.6	27.3	24.6	28.4	28	23.6
AV (cm/s)	6.32	11.5	12.2	6.17	9.68	11.4
SR	1.04	1.16	1.08	1.01	1.02	1.02
PATH (cm)	31.2	35.1	31.1	30.3	30.8	29.4
MU	3	3	1	2	3	1
XROM (cm)	27	26	2.5	27	26	2.5
YROM (cm)	13	16	29	13	16	29

4.2.4 Two-Dimensional Analysis versus Three-Dimensional Analysis

In general, the 2D analysis and the 3D analysis for Trial 1 were consistent. The most significant differences were the change in the number of MUs detected and the MTs for the reaches, which was attributed to the movement onsets and offsets changing in the analyses. Some differences were noted in the 2D and 3D analyses for Trial 2. The number of MUs changed for reach 1 and SR and PATH changed for reach 2 when the Z axis was excluded from the analysis.

Both 2D analyses demonstrated that the exclusion of the Z axis had some effect on the values reported by the computations of the toolbox functions. However, it also revealed that when only the planar directions were analyzed, the changes in movement due to the non-planar direction could not be accounted. As mentioned earlier, children with UE impairment may make compensatory movements in the non-planar direction, as a consequence of their impairment. The web cam will not be able to capture those movements, but depending on which outcome measures a clinician is interested in, capture of movement in the non-planar direction may not be necessary. Overall, the 2D data did not deviate greatly from the 3D data, nor did the results of the analysis. Therefore, it has been determined that the toolbox functions can be used to assess, detect, and quantify changes in 2D and 3D. The final question that remained was whether the 2D data obtained from the web cam looked like the 2D data obtained from FOB for both trials.

4.2.5 Web Cam Data versus Two-Dimensional Flock of Birds Data

To determine whether 2D data collected from the web cam looked like the 2D data obtained from the FOB analyses, the experimenter made several reaching movements in the plane of the web cam. The reaching movements were similar to those generated in the reaching task, so the final reaching trajectories looked like triangles. The trajectories captured by the web cam are depicted in Figure 4.5. Comparing those trajectories to the 2D trajectories of Trial 1 (Figure 4.6a) and Trial 2 (Figure 4.6b), all three plots are similar. The trajectories in Figure 4.5 are several triangles overlaid on each other, created from making many reaching movements. The trajectories in Figure 4.6 are a single triangle formed from the three directional reaches. The triangles seen in Figure 4.6 are not oriented in the same manner as those seen in Figure 4.5 because the reaching task with FOB was conducted in the horizontal plane, while the reaching task with the web cam was conducted in the vertical plane. Since the web cam data looked like the 2D FOB data, the web cam can be used as a data collection tool.

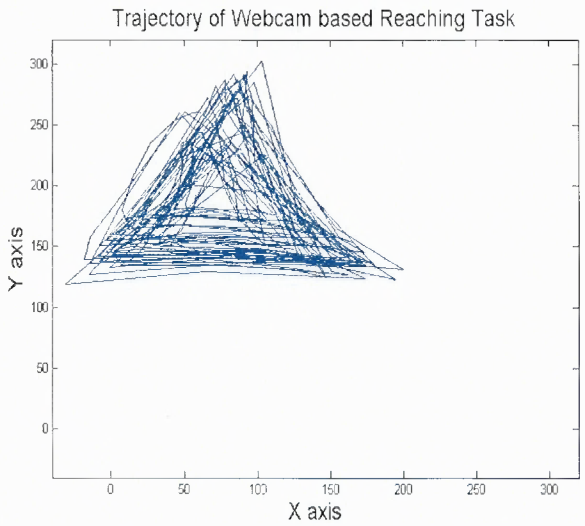
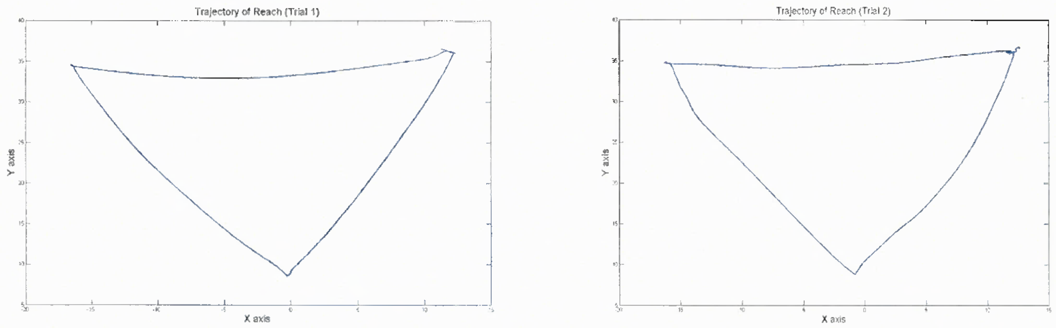


Figure 4.5 Trajectories of reaching tasks captured by the web cam.



(a)

(b)

Figure 4.6 Two-Dimensional FOB Trajectory for Trial 1 (a) and Trial 2 (b).

4.3 Recommendations

The purpose of Hands-Up is demonstrate that children with UE impairment can use a VR gaming platform, provided certain adaptable features are included. Therefore, the effectiveness of the toolbox should be further evaluated by conducting a study with children who have spastic CP or severe UE impairment using Hands-Up. The children would be exposed to Hands-Up for 2 - 3 times a week for 3 - 4 weeks. The toolbox would be used with a reaching task to assess how children with CP and UE impairment typically reach. The toolbox would also be used to quantify any changes or improvements in their movement due to increased game play.

The toolbox is a work in progress and will be updated as more methods for determining certain parameters are found in the literature. The method of designating movement onsets and offsets will be further revised because it is likely that the two small peaks considered part of reach 2 in Trial 1 were not actually part of Trial 1. It seems likely that the first small peak is part of reach 1 and the second peak is part of reach 2. The method implemented with the toolbox was useful in quantifying the data, but a more adequate method should be used. A function for determining the duration of holds should be developed as well. In this study, the duration of holds was computed manually. The toolbox can teach clinicians about kinematics, but if they are not familiar with MATLAB, they may have concerns with using the toolbox functions. Although the toolbox functions are well commented and will be documented for future use, a pre-made script featuring analyses based on selected toolbox functions of interest can be written and the values can be reported to the command window. Once the toolbox functions have been finalized, the final deliverable will a Graphical User Interface (GUI), which will allow analyses with the toolbox functions to be more user-friendly.

4.4 Future Use of the Kinematics Toolbox

The toolbox has several uses beyond Hands-Up analyses. Although it was developed to measure the clinical effectiveness of Hands-Up, it has the potential to be used with 2D data collected from other VR gaming platforms, like the IREX and the EyeToy. To demonstrate the versatility of toolbox, it was validated with data collected during a reaching task. It could have been used with any reaching task. Since the functions in the toolbox were selected because they are measures that are important in clinical rehabilitation, the toolbox can be used to teach others how kinematic data can be processed and quantified.

CHAPTER 5

CONCLUSIONS

In conclusion, a toolbox of functions has been developed for the analysis of Hands-Up video games. Although it was primarily designed for the Hands-Up platform, it was validated with data collected during a reaching task, demonstrating its versatile use. The functions incorporated in the toolbox were sensitive enough to detect and assess changes in movement. The functions were used to quantify the data collected and determine the intent of a participant who generated different types of reaching patterns. As an additional demonstration of the toolbox's versatility, it has the potential to be used with other VR gaming platforms and other types of reaching tasks. Lastly, it was determined that the web cam used with Hands-Up may be a viable data collection tool. This makes Hands-Up an ideal VR gaming platform, meeting a need of pediatric UE rehabilitation.

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