Proceedings of the IEA 2000/HFES 2000 Congress

COLLABORATIVE WORK USING GIVE AND TAKE PASSING PROTOCOLS

A.H. Mason & C.L. MacKenzie
Simon Fraser University
Burnaby, British Columbia, CANADA

To effectively design computer simulations of shared environments, an understanding is needed of the basic informational requirements and underlying movement patterns generated by two people collaborating in these environments. Results from this study indicate that when passing objects in a natural environment, the fundamental movement patterns seen during simple grasping tasks are altered to accommodate the collaborative nature and social constraints of the task. When giving objects, although subjects reach further they reach more quickly than when the objects are taken. This result may indicate a social consideration taken by the passer to move quickly and efficiently over a long distance to transfer the object to the receiver. Thus, the receiver does not have to travel as far or as fast to receive the given object. However, when objects are taken, passers move more slowly and lift the objects higher. This result may indicate that the passer times their movement so that they are not waiting at the end of their movement for the receiver to reach the target. Thus, although the result of the task is the same (the receiver obtains the object), the underlying movement patterns differ with the goal and social constraints of the movement. These results may be used to develop predictive algorithms when designing virtual and augmented environments. Future experiments will concentrate on the nature of visual and haptic information required for both the passer and receiver to effectively perform a passing task in an augmented environment.

INTRODUCTION

Collaborative activity is fundamental to human movement and social behavior. We collaborate with others in both our home and work environments in the course of daily life. Looking to the future, we may also collaborate with a co-located or remote co-worker via a virtual or augmented environment. In these environments, physical, augmented and virtual objects could be manipulated and shared using haptic, audio and graphic computer technologies. Before we can build effective "collaborative virtual environments" we must first understand the nature of the information needed for collaboration.

Studies have been conducted to understand human movements in natural (see MacKenzie & Iberall, 1994 for review) and in augmented environments (Graham & MacKenzie, 1996; Wang et al., 1998). As well, research has been conducted to understand the benefits of collaborative activities for effective work and learning (Inkpen et al., 1997; Suzuki & Kato, 1995). However, little is known about the underlying movement patterns generated when two people collaborate within a physical space. This information will be essential for modeling and optimizing the hardware and software requirements of virtual environments. Thus, the goal of this experiment is to gain an understanding of the fundamental movement patterns generated by two people as they perform a collaborative passing task in a natural environment.

METHOD

Participants

Sixteen, healthy, right-handed, human volunteers with normal or corrected to normal vision provided informed consent and participated in this study. Ethical approval from the Simon Fraser University Office of the Vice President, Research was obtained before testing began. Subjects were paid ten dollars for participation in the study.

Task

Participants performed a collaborative passing task. This task represents a basic collaborative activity where movement and communication are required of both performers for the task to be completed successfully. For each trial, one participant in the pair played the role of passer, while the second participant played the role of receiver. Using the right hand, the passer reached for, grasped and transported an object toward the receiver in either the *give* or *take* protocol. For the *give* protocol, the passer was instructed to grasp and lift the object and then "give" the object to their partner. The partner was instructed to receive the object with their right hand and replace it in the target position. For the *take* protocol, the passer was instructed to grasp and lift the object, while their partner was instructed to "take" the object with their right hand and replace it in the target position. Although the result of both the *give* and *take* protocols is the same (i.e. the receiver obtains the object), the subtle difference between the *give* and *take* passing tasks allows us to assess the effects of task goal and social protocol on passing behavior.

At the beginning of each trial, the subjects sat facing each other across a table. They were asked to rest their right hands on the start position, which was in line with their right shoulders (see Figure 1). The object was located 18 cm in front of each starting position.

Each subject played the role of passer and receiver (2 conditions) and performed the task by *giving* and *taking* (2 protocols). A total of forty trials, with ten trials in each of the four conditions listed above, were performed.

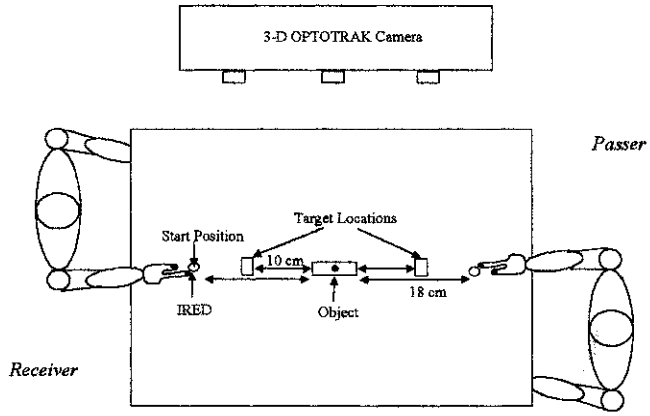

Figure 1: Schematic of experimental setup. Both subjects started with their index finger and thumb pinched and positioned on a start location. The passer reached toward and grasped the object and passed it to the receiver in either the *give* or *take* protocol. Once the object was passed, the receiver replaced the object on the target location. The 3-D positions of infrared markers positioned on the fingers and object were sensed by the OPTOTRAK camera.

Apparatus

Kinematic measurements of both the subject and object movement trajectories were collected using an OPTOTRAK 3-D motion analysis system (Northern Digital Inc., Waterloo, Canada) which monitored infrared emitting diodes (IREDs). IREDs were positioned on the right index fingers and thumbs of both subjects and a fifth IRED was positioned on the rectangular wooden block (6.8 cm X 3 cm X 3 cm). The camera sensed 3-D position data at 200 Hz and transferred it to a Sun workstation for later analyses. Copper contact plates were positioned on the two faces of the block which served as the grasping surfaces. Thin insulated wires were attached to the index fingers and thumbs of the two subjects. This caused a circuit to close when the copper plates positioned on the block were contacted. The contact signal was transferred to a personal computer by means of an A/D converter, which was time synchronized with the 3-D position data being measured from the IREDs.

Data Processing and Analysis

Each trial was divided into two phases. The timeline in Figure 2 illustrates the phases in a typical trial including the kinematic events that mark their start and end points.

Phase 1. This phase describes the kinematic events generated by the passer when transporting the object from the start location towards the receiver. This phase starts when the passer first contacts the object and ends when the receiver makes contact with the object.

The following dependent measures were used to describe Phase 1: movement time (MT), peak velocity (PV), time to peak velocity (TPV), time from peak velocity (TFPV), peak displacement in the forward direction (Ydisp), and peak displacement in the vertical direction (Zdisp).

Phase 2. This phase occurs while the receiver moves from the start position to make contact with the approaching object. Phase 2 starts when the receiver first lifts their hand off the start position. Phase 2 ends when the receiver first touches the contact plate on the object. The following dependent measures were chosen to describe the kinematic events occurring in Phase 2: MT, PV, TPV, and TFPV. It was not necessary to repeat the Ydisp and Zdisp dependent measures for the receiver. Ydisp for the receiver can be calculated by subtracting the total forward displacement of the receiver from the Ydisp of the passer. The Zdisp of the receiver matches the Zdisp of the passer.

Each of the dependent measures for the two phases were submitted to univariate one way (protocol: give, take) repeated measures analyses of variance (ANOVAs). An a priori alpha level was set at $p < 0.05$.

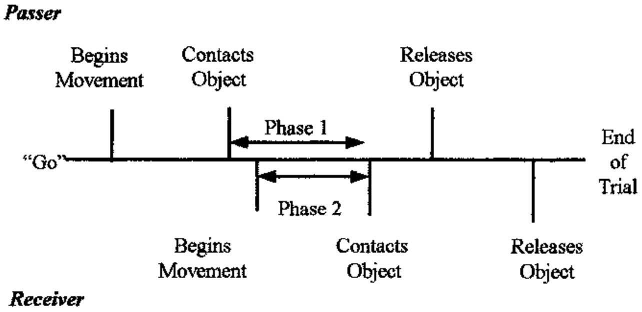

Figure 2: Phases and kinematic landmarks during a trial. Note that on average the receiver begins their movement after the passer has made contact with the object. On occasion, the receiver begins before passer contact.

RESULTS

Phase 1: Passer

Statistical analyses revealed a protocol main effect for MT ($F_{1,15}$=5.0, p=0.04). The passer spent significantly less time transporting the object to the receiver when using the *give* protocol than when using the *take* protocol. This shorter movement time for the *give* protocol was characterized by a higher peak velocity than for the *take* protocol ($F_{1,15}$=6.5, p=0.02). Figure 3 illustrates results for both movement time and peak velocity.

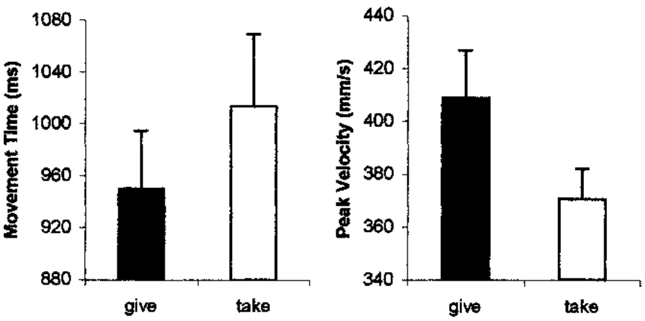

Figure 3: Phase 1. The passer transported the object longer when passing in the *take* protocol than in the *give* protocol. However, this longer movement time in the *take* protocol was characterized by a lower peak velocity.

The passer transported the object significantly further toward the receiver in the *give* protocol than in the *take* protocol ($F_{1,15}$=73.8, $p<0.01$). However, the passer lifted the object higher in the *take* protocol than in the *give* protocol ($F_{1,15}$=7.81, $p=0.01$). These results can be seen in figure 4.

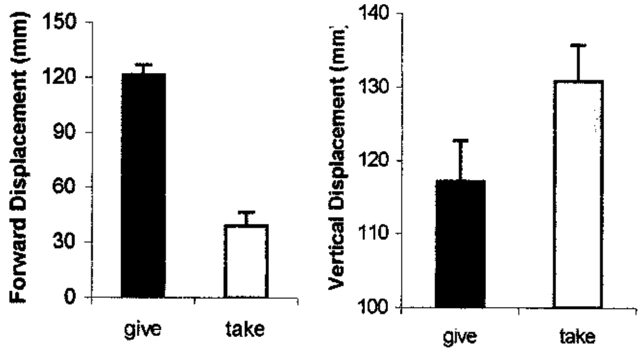

Figure 4: Phase 1. In the *give* protocol, the passer transported the object further. However, the passer lifted the object higher in the *take* protocol than in the *give* protocol. Note axes have different scales.

Although subjects spent a similar amount of time reaching peak velocity for both the *give* and *take* protocols ($F_{1,15}$=3.02, $p=0.10$) they spent a significantly longer time after peak velocity in the *take* protocol than in the *give* protocol. ($F_{1,15}$=12.81, $p<0.01$). Figure 5 illustrates this result.

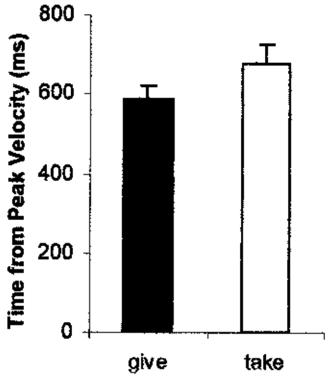

Figure 5: Phase 1. The passer spent a significantly longer time decelerating toward the receiver in the *take* protocol than in the *give* protocol

Phase 2: Receiver

This phase describes the kinematics of the receiver's hand as they move from the start position to receive the object. Statistical analyses revealed a significant main effect of the *give/take* protocol on movement time ($F_{1,15}$=18.25, $p<0.01$). Subjects spent more time reaching for the object in the *take* protocol than in the *give* protocol (see Figure 6). The longer movement time for the *take* protocol was also characterized by a greater peak velocity than for the *give* protocol ($F_{1,15}$=33.15, $p<0.01$). As well, subjects took a longer time both reaching peak velocity ($F_{1,15}$=9.64, $p<0.01$) and decelerating from peak velocity ($F_{1,15}$=15.2, $p<0.01$) in the *take* protocol than in the *give* protocol. Figure 7 illustrates the temporal results for peak velocity in phase 2.

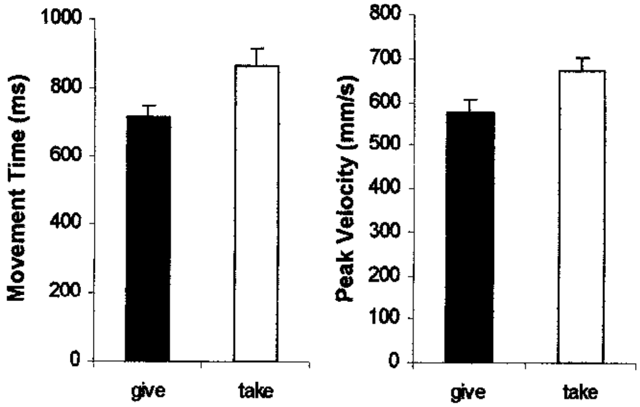

Figure 6: Phase 2. The receiver took significantly longer reaching for the object and had a higher peak velocity in the *take* protocol than in the *give* protocol.

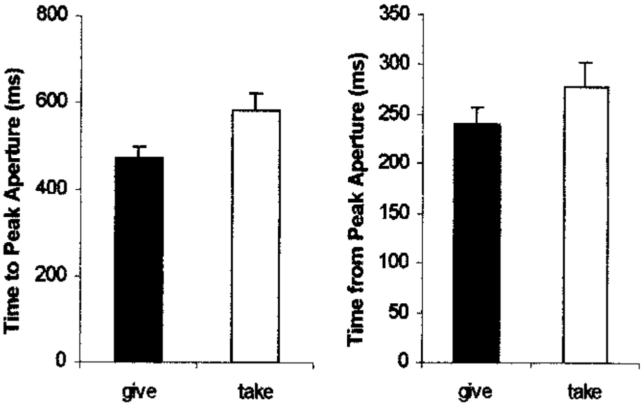

Figure 7: Phase 2. The receiver reached peak velocity later and spent longer decelerating in the *take* protocol than in the *give* protocol.

DISCUSSION

Fundamental Movement Patterns

Taken together, results for the passer and receiver give us some indication as to the fundamental movement patterns and underlying social interactions that occur during the performance of a collaborative task.

In this experiment, we found that when *giving* an object to a partner, people transport the object further toward their partner, and they take less time to make that movement than when the object is *taken* from them. This result is contrary to evidence found in the motor control and human computer interaction literature regarding the effects of target amplitude on movement time (Fitts', 1954; MacKenzie et al., 1987; Graham & MacKenzie, 1996). It has been shown that when reaching to a further target, people take longer. However, we also found that people reached a greater peak velocity when *giving* the object than when the object was *taken*. Thus, for *giving* it appears that people reached further in a shorter movement time by significantly increasing the velocity of their movement. These results indicate that the well documented movement patterns produced in simple unimanual reaching and grasping tasks (see MacKenzie & Iberall, 1994) are not produced when objects are passed to partners. When two people are involved in the prehensile movement, it is necessary to ensure that both people have sufficient time to make their movements. However, in order to ensure that movements are made efficiently, it may also be important to plan the movements so that no time is wasted waiting for the other person. By speeding the *giving* movement the passer may have been attempting to ensure that the receiver did not have to wait for the object at the end of the movement. Thus social protocol may be an important factor when movements are made between partners.

When the object was *taken*, the passer transported the object higher than when *giving* the object. This may have occurred because the passer was aware that the receiver would need sufficient time to reach for the object. In the *take* protocol, the receiver had to travel much further toward the target. By lifting the object higher, the passer may have been trying to avoid waiting for the receiver at the end of the movement. Thus, although the result of both the *giving* and *taking* movements are the same, the nature of the task is clearly different. Both the passer and the receiver likely use information to anticipate and alter their movement trajectories to accommodate their partner and the goal of the task.

Previous research in motor control has shown that when a grasping task is more complex, people spend more time decelerating toward the target than in less complex movements but they spend relatively less time accelerating (Marteniuk et al., 1990). In this experiment, time from peak velocity was found to be greater for both the passer and receiver in the *take* protocol. This result is somewhat puzzling. The *give* protocol requires that the receiver intercept a quickly moving target, while in the *take* protocol, the target should be relatively still when the receiver contacts it. Thus, at least for the receiver, the *give* protocol would appear to be a more complex task. These results may have occurred due to timing constraints when the object was given. It is possible that because of the complex timing required in the *give* protocol, neither the passer nor the receiver were able to anticipate what their partner might do and slow their movements adequately. This would result in greater force generation on the object when passing in the *give* protocol. Perhaps, both subjects used their partner's action or the object as a mechanical stop when the object was *given*, while in the *take* protocol, each partner intentionally slowed their movement down using muscular force. This hypothesis will be tested in future experiments.

Implications for Virtual and Augmented Environments

Currently, the realism within augmented and virtual environments is limited due to the inherent lag when using sensor based information to draw graphics. With current technology, it is impossible for any system to display graphics based on movement with less than 1 frame of lag at 60 Hz. While this time delay may appear to be non-significant, it is perceptible by the human user. One possible solution to this problem is to use data collected from human movement studies to mathematically model and predict upcoming movements. These predictive algorithms must be based on our knowledge of movement kinematics in various situations. To compute these predictive algorithms we must first understand fundamental human movement patterns in a variety of simple and complex situations. Experiments such as the one described above will begin to build the databases of knowledge on human movement in collaborative settings.

Future Work

Having completed baseline tests of collaborative passing in natural environments, we can now focus on collaboration in augmented environments. The goal of future experiments in the Virtual Hand Laboratory at Simon Fraser University will be to manipulate the visual information available about the passer and the object being passed. This experiment will allow us to assess what the receiver must be able to see about his/her partner and the object for effective collaboration. As well, we intend to measure how force generation on augmented objects is affected by a collaborative passing activity.

ACKNOWLEDGMENTS

This research was supported by NSERC, the School of Kinesiology and the Centre for Systems Science at Simon Fraser University. Thank you to Elaine Lee for help with data analysis.

REFERENCES

Fitts, P.M. (1954) The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 47, 381-391.

Graham, E.D. & MacKenzie, C.L. (1996). Physical versus virtual pointing. Proceedings of CHI '96, ACM Press, 292-299.

Inkpen, K., McGrenere, J., Booth, K.S., & Klawe, M., (1997). The effect of turn-taking protocols on children's learning in mouse-driven collaborative environments. Proceedings of Graphics Interface '97, 138-145.

MacKenzie, C.L., Marteniuk, R.G., Dugas, C., Liske, D. and Eickmeier, B. (1987). Three dimensional movement trajectories in Fitts' task: Implications for control. Quarterly Journal of Experimental Psychology, 39A, 629-647.

MacKenzie, C.L. & Iberall, T. (1994) The Grasping Hand. Amsterdam: North-Holland.

Marteniuk, R.G., MacKenzie, C.L., Jeannerod, M., Athenes, S. & Dugas, C. (1987). Constraints on human arm movement trajectories. Canadian Journal of Psychology, 41, 365-378.

Suzuki, H., & Kato, H. (1995). Interaction-level support for collaborative learning: AlgoBlock - An open programming language. Proceedings of CSCL '95, 349-355

Wang, Y & MacKenzie, C.L., Summers, V, & Booth, K. (1998). The structure of object transportation and orientation in human-computer interaction. Proceedings of CHI '98, ACM Press, 292-299.