Predictability or Adaptivity? Designing Robot Handoffs Modeled from Trained Dogs and People

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ABSTRACT
One goal of assistive robotics is to design interactive robots that can help disabled people with tasks such as fetching objects. When people do this task, they coordinate their movements closely with receivers. We investigated how a robot should fetch and give household objects to a person. To develop a model for the robot, we first studied trained dogs and person-to-person handoffs. Our findings suggest two models of handoff that differ in their predictability and adaptivity.

Categories and Subject Descriptors
H.m [**Information Systems**]: Miscellaneous

General Terms
Human Factors

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Retrieval, hand-offs, coordination, adaptive, predictability

1. INTRODUCTION
As the field of assistive robotics advances, robots will eventually assist with tasks such as helping disabled people at home. Although every disability is different, physical disabilities typically involve functional limitations such as an inability to retrieve the newspaper or fetch a soda. If a robot is to help in home environments, it must be able to help a person achieve these goals, and detect deviations that could be indicative of changes in goals or context, such as busyness or the presence of visitors. A large number of computational techniques have been developed to represent and generate structured plans and to change plans in dynamic physical environments, but less is known about changing plans according to changes in a person's immediate context and task.

Being able to change plans involves adaptivity, not just in choosing the tasks to be performed (e.g., pick up object x instead of object y), but also in how tasks are performed. For example, if a robot is fetching a magazine for a person, should the robot place the magazine on the table because the person is busy eating, or should the robot place the magazine in the receiver's hands? In this research, we asked what kinds of adaptivity a robot would need to successfully coordinate object handoffs to a person. Would the robot need to detect all of the cues that people exchange with other people, or would a simple preset handoff routine suffice? Would there be an advantage to predictability? Finally, what would be the implications of these different levels of adaptivity for people's perceptions of the robot and their willingness to collaborate with it?

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2. STUDY 1: DOG-HUMAN HANDOFFS
We visited a dog obedience training center located in Pittsburgh and videotaped eight (advanced and mid-level) pairs of dog handlers and their dogs practicing obedience retrieval routines. We focused on a particular phase of retrieval, delivering an object to the handler. We asked handlers to drop or place a dumbbell, cotton glove, doll, or ball on the floor and ask the dog to bring it to them. Each dog-handler pair performed two to four handoff trials, resulting in a total of 32 trials.

At the point of handoff, handlers and their trained dogs share protocols that specify behaviors to hold the object, to signal each other's intent and readiness for exchange of the object, and to end the procedure (Figure 1). The protocols include how to hold objects (e.g., dumbbell held in the middle, not at the ends), where to be at point of delivery (e.g., facing the handler), and how to release the object (e.g., held until the handler gives a command to release).

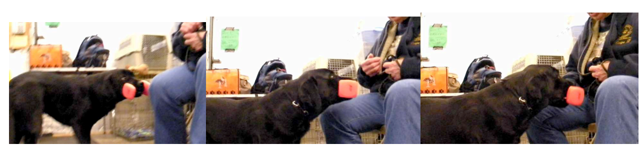

Figure 1. Trained dog delivering dumbbell to handler. Note eye contact and dog's adjustment to sitting position of handler. The dog releases the dumbbell when the handler grabs its end.

3. STUDY 2: HUMAN-HUMAN HANDOFFS
We observed five pairs of participants handing objects to one another in an eat-in kitchen while doing two tasks. Each person in the pair took turns handing objects to the other. For each of two scenarios, they transferred 10 objects, resulting in 40 trials for each pair. The session took about 30 minutes to complete, and was videotaped.

Carrying: We had asked givers to carry objects as though they were caretakers. Sixty-six percent of the time, participants used both hands when carrying objects, even though the objects used in our experiment were not heavy. All givers used two hands for the tray; a majority used two hands to carry the book and cup, and about half to carry the apple, coins, newspaper, pens, plate, pot, and the water bottle. It is possible that the two-handed carrying

Figure 2. Receiver reaching for tray.

behavior was a response to our asking the participants to role play a caretaker.

Signaling: All givers gave off cues (whether intentionally or not) that they were about to deliver an object.

Givers signaling readiness. Givers who were carrying an object with two hands, just prior to coming to a stop in front of the receiver, signaled a handoff by dropping a hand and reaching out with the object (only 6 exceptions out of 123 observations of two-handed carrying). Givers using one hand, reached out with the object. Givers typically started reaching out before they came to a stop near the receiver. However, they did not perform this early reaching behavior if the receiver was not paying attention, which leads us to believe that reaching out was used as a signal.

Receivers signaling readiness. The receiver often signaled receptivity by making a "grabbing" hand gesture with one arm or two (see Figure 2). We saw this behavior in receivers significantly more often when givers were carrying a cup, pens, or a tray with a glass of water on it. These objects are more likely to be problematic if dropped (as compared with a newspaper or book, for example), so it makes sense that receivers should nonverbally reassure givers they are ready to receive the handoff.

The most common coordination pattern (58% of trials) was givers communicating a desire to hand over an object by coming close to the receiver. The giver moved the hand holding the object toward the receiver's hand, and the receiver then would take the object. The second most common coordination pattern (34% of trials) happened when givers reached out the hand with the object at a point where the distance between the two participants was further apart than the sum of their two arm lengths. In these situations, the participants closed the gap somewhat but were further apart when the object was actually transferred. In those cases, the receiver also reached out an arm to grab the object. The giver would then move his or her hand toward the receiver's hand. Some receivers exhibited very cooperative behavior by leaning their bodies forward while reaching out their arms. The third pattern, although less common (7%), happened when the receiver waited with a grabbing hand gesture but was not looking at the giver. The givers came close to the receivers who did this and put the objects into the receivers' hands. The two less common patterns were more frequent when receivers were standing (chi square $[2, 158] = 5.7$, $p = .05$), suggesting that either the receiver's lack of anchoring (to a chair) and/or the busyness of the receiver (sorting items into a box) led to more signaling and intricate coordination between givers and receivers.

Handing off: On average, the distance between the giver and the receiver did not vary across objects. Also, all the objects were transferred at a height that was below the receiver's neck, (chest level or below). A majority of the object handoffs were above waist. In 24 turns, givers turned a newspaper, book, cup, or pot so that receivers could more easily receive the object. For example, the giver would rotate the cup so that the receiver could grab the handle. This phenomenon occurred in 30% of the turns for those four objects.

4. Design of Robot Handoff Behavior

We drew from the findings and observations from Studies 1 and 2 to derive sets of design features for informing the design of a robot's handoff shown in Table 1.

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Table 1. Design features to inform the design of human-robot handoffs.

Model	Phase			Levels of adaptivity
	Carrying	**Signaling**	**Handoff**	
Fixed model (based on trained dog handoffs)	Adaptive location and orientation to receiver Object carried with consistent orientation	Verbal cue initiates handoff event	Position close to receiver Waits for verbal command and grasp of object	Location of receiver
Adaptive model (based on human handoffs)	Adaptive location and orientation to receiver One hand vs. two hand carry Varying orientation of object	Behavioral cue initiates handoff event Shifts item to one hand Reaches arm out to signal, while still moving Pauses if receiver is busy May lean towards receiver	Position close to receiver Orients object to accommodate receiver Waits for receiver readiness Moves hand with object to meet receiver's hand Puts object on table if receiver is too busy	*Ergonomics, physical factors*: Location of receiver; Position of hand *Task factors:* Interruptibility of receiver; receiver's focus of attention; types of objects and their affordances *Social factors:* Social norms (e.g., politeness)