Designing Co-located Tabletop Interaction for Rehabilitation of Brain Injury

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Abstract. This paper surveys emerging design research on co-located group interaction with tabletop displays as an approach toward developing an upper-limb movement rehabilitation system for acquired brain injury (ABI). Traditional approaches and newer virtual reality interventions for physical therapy tend to focus on individuals interacting one-on-one with a therapist in a clinical space – this is both labor intensive and costly. Co-located tabletop environments have been shown to enhance the engagement of users, translating to skill acquisition. We describe the principles of group interaction that inform our understanding of motor rehabilitation using interactive media; explore four constructs from interactive tabletop research that may influence the design of co-located systems for rehabilitation: 1) physical space, 2) group awareness, 3) territoriality, and 4) interaction simultaneity; and consider how each construct can be expressed in particular design solutions for rehabilitation of ABI.

Keywords: Co-located, Group Interaction, Tabletop Display, Movement Rehabilitation, Acquired Brain Injury.

1 Introduction

Acquired brain injury (ABI) from stroke and traumatic brain injury (TBI) is a major global health issue [1]. Neurological trauma can lead to a variety of physical, cognitive, emotional and behavioral deficits that may have long-lasting and devastating consequences for the victims and their families. The capacity of health services to cater to large numbers of clients with differing needs is limited. Traditional approaches to physical therapy require intensive one-to-one work over an extended period using a variety of props, in relatively large workspaces [45]. Whilst time-on-task is a good predictor of recovery, a 1:1 therapist-client ratio is labor intensive and cost prohibitive.

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Accordingly, enhancing physical rehabilitative processes in the early stages following a brain injury is one of the great challenges facing therapists given the huge demands on the health system.

There is now strong evidence to support the use of group-based rehabilitation as a way of leveraging therapy and reducing health care costs [9]. For example, circuit class therapy has been shown to reap significant mobility outcomes for ABI in a group setting, regardless of the severity of injury and chronicity [49]. Indeed, studies have suggested that group-based therapy provides additional benefits through observational learning [44], and fostering peer support [11].

The way computers can mediate and support work in a group environment has become a research domain in Computer Supported Cooperative Work (CSCW), a sub-field of Human Computer Interaction (HCI). The advent of large-format interactive walls and tabletop displays heralded the potential of computers to facilitate the work practices of small teams co-located around the same physical interface [6], [48]. In particular, tabletop displays can support face-to-face multiuser interaction through the physical affordances of the horizontal interface or the users' mental models of working around traditional tables [42]. Tabletop displays can support a broad range of user interactions such as multifinger touch, hand gesture and simultaneous manipulation of physical objects [17], [47], [50], lead to collaborative learning in a group setting [22], [37], and foster multimodal communication between users [10]. For example, tabletop computer games have been shown to support social competence training for children with Autism Spectrum Disorder [13].

How group work using tabletop technology can enhance motor rehabilitation of ABI is relatively unexplored. Our research seeks to address this gap by exploring how social aspects of group interaction and physical affordances of tabletop displays may be exploited to enhance the design of environments for such rehabilitation. We consider design research on tabletop displays, social psychological literature on group-based interaction, concepts from ecological psychology, and work in CSCW to forge an integrated view of the possibilities of co-located interactive workspaces. In particular, we examine the advantages of tabletop interfaces based on our observation of patients from prior research [29] and identify areas of potential development.

2 Prior Work

2.1 Elements: A Single-User Tabletop Workspace

As reported elsewhere, our prior work called Elements is a single-user interactive tabletop environment used to enhance upper-limb rehabilitation for TBI patients [7]. The physical design of the environment is comprised of a tabletop graphics display, four soft graspable objects used by the patient (i.e. tangible user interfaces, TUIs), a computer vision camera to track the position of the TUIs, and a secondary display for the therapist to control the task parameters presented to the patient.

A suite of interactive software applications provides the patient with tasks geared toward reaching, grasping, lifting, moving, and placing the TUIs on the tabletop display. Real-time audiovisual feedback is designed to help the patient refine their movements over time. Patients can also manipulate the computer-generated feedback to create unique audiovisual outcomes. For example, in one environment the patient might feel pleasure from being able to mix and manipulate sound and colorful graphics in an aesthetically pleasing way. The overall system design provides tactility, texture, and audiovisual feedback to encourage patients to move in response to external cues or in a self-directed way. The various feedback mechanisms provided by the system assist patients and therapists monitor their progress and plan for improvement over time. Our preliminary findings suggest that performing tasks on the Elements system is a viable adjunct to conventional physical therapy in facilitating motor learning in patients with TBI [28-29].

2.2 The Advantages of Tabletop Interaction for Rehabilitation

Interactive tabletop displays offer several unique advantages for motor rehabilitation. Foremost, the tabletop display supports upper-limb interaction as the main form of user input. Approximately 85% of brain injured patients suffer acute impairment to their upper body, so a majority of patients rate the return of upper-limb function as a high priority [25]. The horizontal display and TUIs logically constrain user movement within a defined (planar) area above the table. The task constraints include the ways in which the TUIs can be held, moved, and stabilised in relation to the virtual environment projected on the tabletop display and the audiovisual feedback. By reducing the number of alternative actions that can be performed by the patient in the early phase of recovery we make explicit the functionality of the user interface to perform a certain task or function. Varying the task and environmental constraints is designed to increase the patient's ability to plan and initiate movements over time.

Secondly, tabletop environments support multimodal forms of communication between co-located users [33]. For example, the configuration of the Elements system enables a close visible relationship between the patient and the therapist. The therapist can supervise the patient's activities and provide feedback, encouragement and prompts. Patients can explore, learn and share how new movements can be performed and validate these actions in direct communication with the therapist.

Thirdly, tabletop interaction supports an embodied, first-person view of performance that capitalizes on our physical skills and our familiarity with real-world objects [8]. A key feature of tabletop displays is their capacity to integrate and support the manipulation of physical objects such as TUIs [20]. TUIs placed on the tabletop are used as the primary means for users to control the Elements interactive environment. The shape and physical weight of each TUI offers the patient varying perceptual motor cues for action [12].

3 Design Characteristics of Tabletop Interaction

In this section we focus on related work on tabletop interface design that supports co-located forms of user interaction. We identify the socio-physical characteristics of co-located workspaces that designers should consider when developing rehabilitation applications. We describe four main characteristics or factors – physical space, group awareness, territoriality, and interface simultaneity – and outline how they can be exploited in the design of therapeutic tasks in a group setting.

3.1 Physical Space

The physical space surrounding tabletop displays can influence the dynamics of collocated interaction. For example, the spatial orientation of users around tabletop displays has been shown to influence how individuals comprehend information, coordinate actions between one another, and communicate in a collaborative setting [23]. Tasks may support the arrangement of users sitting side by side; but other tasks may support users sitting opposite one another depending on the orientation of the information displayed. Other findings have shown user position affects the level of participation across a tabletop surface [36]. The level of participation is partially dependent on how well a participant is able to physically reach across the table [46]. As well there is a generalized preference for users to interact within the region of the display closest to their body [43]. This has basic implications for the design of tabletop interfaces that enhance group cohesion and provide space for collaboration. The software design will affect how groups of participants partition the tabletop display and whether this is scaled optimally to the physical ability of the users.

Other physical attributes such as the shape and width of the non-interactive edge surrounding the display can assist how interactivity is managed [27]. For example, the size of the rim around the tabletop display can enable users to rest their arms without interfering with the interactive area of the display. The rim can also influence how physical resources (e.g., papers, TUIs) are arranged and selected for use both on and off the display during performance [27].

The table must have sufficient height and size to comfortably accommodate the group. Users should be able to maneuver around the table and sit or stand comfortably facing toward the display for extended periods of time. Many current systems incorporate technology that may render one or more sides of the table unusable. For a detailed review of these systems see Muller-Tomfelde et al [26]. For easy access, active sides of the table should be free of encumbrances such as rear projection equipment or display attachments. Accessibility is a common issue for ABI patients who may have postural difficulty in sitting and standing. Physical obstructions may impact on their level of comfort and interfere with their interactions with others.

3.2 Group Awareness

Awareness is regarded as the first step in self-regulation and plays an important role in skill development [35]. Group awareness is the degree to which people perceive and understand others' existence and activities in a shared task [30]. The ability of interactive tabletops to support awareness of others' actions is often cited as one of the main benefits of collaborative face-to-face learning [37]. Participants can observe and learn from how others are directly manipulating objects. Awareness of what others in a group are thinking and doing is also essential in coordinating collaborative learning and achieving common goals around a shared tabletop. Such learning is effective when the tabletop is a shared resource, participants using gesture and moving icons to communicate their ideas and understanding to others [10].

Communication patterns in co-located groups, including the use of gesture have been examined in various ways [4], [14]. Both communication and participation increase when groups interact around a tabletop display [39]. Tabletop games have been used effectively to develop social skills and foster collaboration in children and adolescents, including those with Autism Spectrum Disorder [3], [31]. Providing shared access to physical and digital artifacts can help maintain group focus and facilitate group awareness [40]. Moreover, tabletop interfaces can be designed to enable more equitable participation and sharing among members of the group [2], [18], [24], [32], although sometimes groups work well together when one person dominates the action [37].

Differences in the way tabletop interactions are designed affect individual and group processes, and thus participants' experiences. Nacenta et al. considered three perspectives in the design of tabletop interactions [30]. The *action perspective* refers to whether local space or shared space is used to provide input for the technique and display the action's output. The *person perspective* differentiates physical and virtual embodiments for people in shared workspaces. The *group perspective* deals with policies and rules that govern interactions and provide support for those participating. The elements of these three design perspectives have differing effects on the criteria used to evaluate interaction techniques. Nacenta et al. found higher levels of awareness when input and output are in shared space, objects are manipulated through direct-input techniques such as touching, dragging, and lifting, and participants are represented by their physical body.

3.3 Territoriality

The notion of territoriality has its roots in both ethology and more recently in evolutionary psychology and ecological psychology. In essence it refers to the spatial area that an individual or group lays some claim to [15]. Related to this is the notion of peripersonal space, which is the perceived boundary within which personal actions are performed [34], as distinct from those of others. These spatial frameworks bias our behavior according to the location of objects in the environment relative to the self and their reward or resource value to the species. Put another way, territorial behavior is bound up with the notion of resource and its proximity.

These resources are traditionally environmental (like food sources or nesting sites), but can also be other valued commodities like a site where a valued object is situated (like a cache of money or jewels) [19]. Importantly, in advanced human behavior, resources can be purely symbolic (like a token that can be exchanged later for some reward). This capacity of the human mind enables resources and the experience of reward to be extended in time; that is, the physical object does not need to be physically present to elicit territorial behavior. However, the symbolic value of a resource can be highlighted by the use of salient physical cues.

Accordingly, a range of non-verbal factors influences territoriality and the notion and experience of personal space. Edward T. Hall delineated at least 6 such factors that influence how humans and non-humans position themselves in relation to each other: visual, touch, kinaesthetic, voice loudness, thermal, and olfactory [16]. This approach has some useful implications for interaction design insofar as some combination of these cues can be manipulated using the display and user interfaces to alter the performer's perception of personal space and territory.

In the sphere of virtual rehabilitation, for example, these non-verbal factors can be manipulated in strategic ways to compensate for the impaired processing capacities of the patient, post injury. For example, sound pitch and/or loudness might be used to signal a form of interaction with a tangible interface, perhaps inviting manipulation on the one hand, or signalling that an approach might infringe on the territory of another person. This scenario can also be imbedded within the context of a game where permitted actions are defined by both physical and symbolic cues.

Research also suggests that the physical size of the tabletop display can impact the social interaction and working strategies among groups of users [41]. For example, physical size may engender a particular style of interaction when there is a clear perception of personal and/or group territory [43]. The table size directly impacts the physical proximity between individuals around a display, which can change how they collaborate when performing individual and group tasks. A smaller table ensures all users can reach every part of the table, which may encourage them to negotiate and collaborate. By comparison, partitioning the display environment and orientating parts of the graphics to each user may support both personal and group spaces on the table and transitions between personal and group work [42].

Territoriality can be used as an organising principle in the design of rehabilitation tasks. The proximity of users should be considered carefully so that interactions within a person's intimate or peripersonal space do not feel socially awkward. The location of the patients and the scale of the workspace, considered together with rules of interaction and the number of resources, can define how a co-located space is utilised and explored in rehabilitation. Depending on the rules by which resources are collected and distributed, different modes of interaction may be afforded, some cooperative, some playful, and some competitive. Each mode of interaction may achieve slightly different therapeutic ends in the realm of motor rehabilitation. For example, competition for resources in a discrete space, under time pressure, may enhance the reward value for patients while also encouraging faster actions. Although little is known about how groups of ABI patients interact with each other in rehabilitation, tabletop displays may offer ways for patients to relearn social skills and sense of personal space which may be adversely affected as a result of their injury.

3.4 Interface Simultaneity

Unlike single user interfaces such as desktop computers, tabletop technology can support multiple interfaces for collaborative work. TUIs can be selected, passed around, manipulated and shared by groups of users [40]. With groups of users comes the possibility for individuals to interact simultaneously with others and the tabletop interface. Concurrent interaction among groups enables a wider variety of collaboration styles, including working in parallel, working sequentially in tightly coupled activities, working independently, and working in assumed roles [42]. Scott et al suggest concurrent interaction enables the user to focus on the task at hand rather than monitoring others in order to tell when the system is available. The Rogers et al. findings indicate that sharable interfaces promote more group participation, highly coordinated forms of collaboration and verbal communication when tabletops support multiple points of interaction. Importantly, they suggest more tangible and accessible interfaces may consequently encourage greater participation from people who normally find it difficult to communicate verbally or those who simply find contributing in a group setting socially challenging.

A key advantage of tabletop displays is that the technology supports tangible interaction using multiple physical input devices and multi-touch input [26]. Conventional interfaces like keyboard and mouse tend to neglect the intrinsic importance of body movement and tangible interaction [5] and limit opportunities for relearning movements among brain-injured patients. Physical input devices or TUIs, however, can exploit multiple human sensory channels otherwise neglected in conventional interfaces and can promote rich and dexterous interaction [21].

The development of these naturalistic interfaces for user interaction is essential to optimise performance and improve access for patients with cognitive and motor impairments [38]. The form factor of the interfaces should take into account the deficits experienced by patients. Brain injured patients frequently suffer perceptual difficulties in auditory and visual functions, perception of objects, impaired space and distance judgment, and difficulty with orientation. High contrast colors and simple graspable shapes for example, may be used in the design of TUIs to assist a visually impaired user individuate each interface and ease cognitive overload.

4 Conclusion and Future Work

We have identified and discussed four key characteristics that can be used to guide the design of multiuser rehabilitation applications using tabletop surfaces. What is both challenging and intriguing for the developer are ways of designing features that leverage the type of therapeutic interaction and efficacy. Such design considerations are particularly important in therapeutic environments where patients may initially be hesitant about working in a group of people they do not know and reluctant to reveal their level of disability. A shared physical space and resources can be structured in ways that assist a patient group to develop an alliance and shared agenda. For example, a simple tabletop game can be set up that requires the group to work together and compete against the computer to score points. For the practitioner, the ability to manipulate the physical workspace (or territories) can, in turn, cater to patients with different needs and skill levels. How patients will collaborate with each other and the possible consequences of participation are less predictable.

The conceptual issues discussed in this paper are a starting point for understanding how to design effective multiuser applications for rehabilitation using interactive tabletops. This presents an avenue for transcending a traditional reliance on single-user applications. By understanding the intrinsic characteristics of shared workspaces, we aim to develop therapeutic group applications using tabletop displays that can maximize patients' potential to "learn from others", to develop social skills and confidence, and to instill motivation to work harder through collaboration and competition with fellow patients. Our principled approach to interface design that supports groups of patients will hopefully make brain injured individuals more willing to persist in rehabilitation, ultimately speeding their recovery.

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