Human-human-interaction for motor learning: A Literature Review

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Abstract

One crucial aspect for robot based therapy devices for motor rehabilitation is how they perform haptic interaction with patients. We believe that understanding of human-human-interaction (HHI) can lead to better design of control algorithms for robotic therapy devices. This paper presents results of systematic literature review in the area of haptic HHI. We aimed to summarize the research findings on haptic HHI which are directly relevant for research in human-robot-interaction (HRI) and find evidences that interactive task performance can contribute to motor learning.

1 Introduction

Stroke is one of the dominant causes of acquired disability. Every year more than 250,000 first-time or repeated strokes occur in Germany [1] and 700,000 in the United States [2]. Robot based therapy is one of the prevalent therapeutic approaches, which often used in hospitals in a combination with manual therapy, since numerous clinical studies showed that patients can benefit from robot based training [3, 4, 5]. Rehabilitation robots physically assist the patient's movement during the session and guide the hand or leg along the learning trajectory so that the movement errors are minimized. This technique is known as haptic guidance and is especially effective for the early phase of learning. But this strategy provides only temporary increasing of performance [6]. According to the guidance hypothesis too much haptic guidance can harm performance increase [7, 8] but reduced guidance leads to better performance after the training phase [9, 10]. An "Assist-as-needed" training strategy can help to avoid negative results and support motor learning. The strategy is realized through control algorithms implemented in the robotic therapy device that determine the interaction between patient and robot. In this case the device supports the patient only if he cannot perform the training task independently and provides an appropriate amount of assistance, so that patient can maximize his effort and some errors are allowed. Some "assist-as-needed" control algorithms were already implemented in rehabilitation robots [10, 12, 13] and tend to have a positive effect on patient therapy [14].

One way to design a safe and natural HRI, which may be beneficial for motor learning, is to model haptic HHI in such type of tasks and create "assist-as-needed" control algorithms based on this model. In our theoretical literature study we investigated whether modelling of haptic HHI could be beneficial for rehabilitation robotics. To summarize the findings on haptic HHI we reviewed experimental psychology and interactive robotics studies. The purpose of this study is (i) to present a survey of experimental studies and research findings on haptic HHI, (ii) to detect possible benefits of haptic HHI for HRI, and in particular for motor learning.

2 Methods

Publications were identified up to October 2013 from electronic databases - IEEE Xplore, SAGE Journals, PSYNDEX, SCOPUS, ASME DC, ACM DL, BioMed Central, PsychInfo, Web of Science and PubMed. Keywords and search algorithm: (("human-human" OR "human-machine-human" OR "human-robot-human") AND (interaction OR coordination OR collaboration OR joint) AND (physical OR haptic OR motor)). The articles were chosen according to the following inclusion criteria: (1) the publication describes an experimental study and (2) the focus of the study is on haptic HHI or human-robot-human-interaction.

3 Results

A total of 5495 articles have been found (Figure 1). After removing the duplicates 4544 publications remained, among which 4454 were excluded based on the title or abstract alone. During the full text review, 74 more articles were excluded.

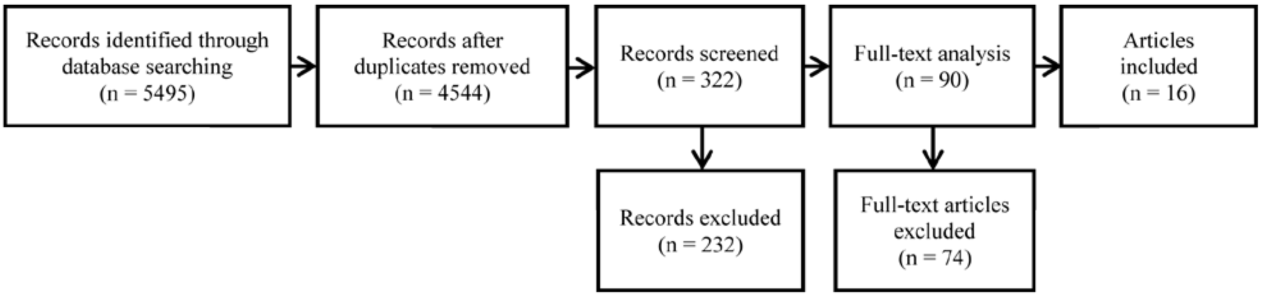

Figure 1. Identification and selection of studies

A total of 16 papers that meet the inclusion criteria were identified (Table 1). As an interactive task for experiments in this studies were following selected: crank-rotation task [15-22], moving a virtual [23-27] or a real object [28], hand-over of object [29], wrist flexion-extension [30]. The specialization principle between interaction partners (e.g. leader/follower) was detected in 12 of 16 articles [15-20, 23, 25-28, 30] and it was found that it leads to better performance compared with interaction without specialisation [25]. In 8 of 16 studies was seen, that task performance in terms of completion time is better for human dyads as for individuals [15-21, 23] and as for human-robot-dyads [19, 20]. In only one study was presented groups and dyads performance in motor learning tasks in comparison with individual performance [21].

Table 1. Results of systematic literature review

Publication	Task	Specialization	Other results
Ueha et al., 2009 [15]	Crank-rotation task (1 DOF)	Dynamical role division: tangential and radial forces	Task completion time is longer for individuals as for dyads; dyads have the same force-division-strategy as individuals
Reed et al., 2004 [16]	Crank-rotation task (1 DOF)	Two types: active – inert dyad, agonist – antagonist	Fitts' low can be applied to symmetrical tasks for individuals and dyads as well
Reed et al., 2005 [17]	Crank-rotation task (1 DOF)	Two types: active – inert dyad, agonist – antagonist	Oscillations of forces decreases with decreasing task completion time; There is a steady dyadic opposition force during the task execution in dyads
Reed et al., 2006 [18]	Crank-rotation task (1 DOF)	Two types: active – inert dyad, agonist – antagonist	Task completion time is longer for individuals as for dyads
Reed et al., 2008 [19]	Crank-rotation task (1 DOF)	Two types: active – inert dyad, agonist – antagonist	Task completion time is longer for human-robot-dyads as for human-human-dyads
Pham et al., 2010 [20]	Crank-rotation task (1DOF)	Dynamical role division: tangential and radial forces	Task completion time is longer for individuals as for dyads; There is a competition of tangential forces between two humans working together
Wegner et al., 1956 [21]	Crank-rotation task (1DOF)	____	Better performance for groups as for individuals was observed for motor learning tasks
Gentry et al., 2005 [22]	Crank-rotation task (1DOF)	____	There are more errors at the high difficulty levels in dyad-condition; a better performance at a minimum-time cyclical aiming task in dyad-condition
Feth et al., 2009 [23]	Moving a virtual object (1DOF)	Classification by energy flow (considers the applied forces and the velocity): energy injecting partner – energy absorbing partner	Performance for the partner condition is better compared to single condition
Groten et al., 2010 [24]	Moving a virtual object (1DOF)	____	Compared to the visual only feedback condition HHI with haptic feedback leads to higher physical effort and higher performance

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Table 1. Results of systematic literature review (continuation)

Publication	Task	Specialization	Other results
Groten et al., 2013 [25]	Moving a virtual object (1DOF)	Two types: leader – follower; partners, that try to adapt to each other	Increasing of effort when preferences in the decision types are opposite; leader-follower specialization leads to better performance as no specialization
Khademian et al., 2007 [26]	Moving a virtual object (1DOF)	Trainer and trainee with different levels of authority	The dominance factor has an impact on task performance; transferring authority to trainee causes generating higher performance indices for the trainee and causes poor performance of the trainer
Takač et al., 2011 [27]	Moving a virtual object (1DOF)	Supervisor – acting agent	Haptic communication strategies: motion copying; steering; impulse control
Salleh et al., 2011 [28]	Moving a real object (2DOF)	Leader – follower	Cooperative task smoothness depends on perceiving different parts of the manipulated object (End and Center case); smoother and more natural motion for the Center case in leftward/rightward and upward/downward direction
Glasauer et al., 2010 [29]	Hand-over of objects (3DOF)	____	The reaction time (RT - duration from lifting the object until the receiving subjects) of hand-over in human-human condition decreases systematically over trials; the RT depends on the expected hand-over position
Melendez-Calderon et al., 2011 [30]	Flexion-extension	Quantitative classification system for haptic HHI: Both try (BT), Drive and Brake (D-B), Flex and Extend (F-E), Drive and stay center (D-sC), Drive and stay flexed (D-sF), Drive and stay extended (D-sE)	Redundancy of effort during human-human-interaction

4 Conclusion

In this review we presented the results of a literature review focused on HHI. A total of 16 publications were found that matched the inclusion criteria. Only one of these articles [21] describes an experiment about influence of HHI on motor learning. Based on this article it can be assumed that working in groups or dyads can be beneficial for motor learning performance for healthy individuals. The review shows limited research on motor learning in cooperation between humans and, therefore, further investigation is required.

Some publications were excluded, because they did not contain detailed information about the underlying experimental methods or were purely theoretical. Articles about joint action without haptic interaction as well as the publications about social collaboration were not included in this review.

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