Non-Dyadic Entrainment for Industrial Tasks

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***Abstract*—In order to achieve efficient collaboration during task completion in groups, temporal alignment is essential, i.e., synchronisation. We believe that efficient entrainment in mixed human-robot teams can positively affect human-robot collaboration. However, few studies have investigated how groups of humans entrain with each other to acquire new knowledge transferable to human-robot collaboration. This paper proposes a study design to get new insights into how dyads and triads of human workers entrain in assembly tasks simulating the industrial context. We argue that the investigation of both dyadic and non-dyadic (i.e., triadic) configurations is essential, as this will give us insights into how, and if, the complexity of reaching temporal synchronisation through entrainment increases with additional actors. Lastly, we propose a follow-up study investigating how the mechanisms utilised in human-human entrainment can be replicated in an industrial robot, ultimately improving human-robot collaboration in mixed teams.**

***Index Terms*—entrainment in mixed human-robot groups, industrial collaboration, non-dyadic HRC, synchronising with robots**

I. Introduction

While the adoption of robots in various sectors is ever-growing (e.g., in the health sector [10], [13], [20], the domestic space [5], [19], or for use in education [6], [12], the growth in one sector stands out: the industrial sector. As the industrial sector (e.g., manufacturing or assembly) is characterised by well-defined—often repetitive—tasks, this context lends itself well to the automation using industrial robots and, more recently, collaborative robots (cobots). More specifically, tasks like pick-and-placing of items or high-volume low-variety assemblies are constrained and characterised by a repetitive nature in a controlled, structured environment with low variability. Furthermore, industrial tasks often rely on non-dyadic cooperation, i.e. cooperation amongst multiple actors. Furthermore, the onset of Industry 5.0 has shifted the primary focus away from purely focusing on the efficiency of production to a more human-inclusive approach, considering worker well-being and involvement [1], [2] as well as human-robot collaboration (HRC) in mixed teams (e.g., [18]).

As recent research has demonstrated (e.g., [15], [21]) collaboration in synchronised human teams brings with it an abundance of desirable effects including: increase in task performance [21], greater feeling of likeability towards collaborators [4], [7], or a greater willingness to cooperate [15], [22]. In order for pairs, groups or crowds to synchronise efficiently, collaborators undergo an entrainment period that leads towards synchronisation [15]. Yet, most studies investigating interpersonal motor synchronisation in non-dyadic settings (i.e., beyond two actors) focus on non-industrial tasks such as clapping [11], walking [22] or finger tapping [4].

In this paper, we argue for the need to investigate entrainment in non-dyadic human groups within one of the fastest-growing domains for robot implementation, the industrial setting. As entrainment is still a relatively new topic of interest within the HRI community, an initial step could be the investigation of human team entrainment using tasks resembling industrial aspects, as in-the-wild studies might yet be too uncontrolled. With the usage of tasks (e.g., assembly, packaging, or pick-and-placing) resembling an actual context of human-robot collaboration, we believe we can increase contextual relevance of the domain studied for entrainment and thereby acquire a deeper understanding of how entrainment, in this specific context, can be transferred to robots, ultimately resulting in a better human-robot collaboration in mixed groups.

II. Background and Related Work

This section will briefly outline characteristics of entrainment, highlight several positive effect thereof, as well as present important lessons presented by previous research for effective human-robot entrainment.

A. *Characteristics of Entrainment*

Entrainment has been widely explored across many disciplines (e.g. cognitive science, biology, and music). In simple terms, entrainment is the process that systems go through to reach synchronisation with a rhythmic signal. This paper focuses exclusively on interpersonal entrainment (entrainment).Phillips-Silver et al. [14] identify three required elements that need to be present in order for entrainment to be possible. These are i) the ability to identify rhythms in the environment, ii) the ability to produce rhythmic signals, and iii) the ability to used sensory information to adjust ones own output based on the perceived input [14].

A study by Rinott et al. [15] categorises all forms of entrainment into one of two categories: *external entrainment* and *mutual entrainment*. During external entrainment, an actor entrains to a signal from its environment (e.g., a metronome or the beat of a drum) where the environmental signal is independent of the actor itself [16]. In contrast, mutual entrainment does not require external stimuli, as a set of actors entrain to each other's actions. Specifically, the input of each actor is the output of from another actor (e.g., a group of people clapping [11]). Entrainment is therefore the process that leads to synchronisation.

While entrainment can lead to synchronisation, synchronisation does not need to be in phase. During e.g., anti-phase synchronisation, one or more actors perform a given action while being opposite to each other, such as the the two partners during a Waltz. On the other hand, in-phase entrainment, can be observed in military marching.

As shown previous research has investigated different characteristics of entrainment. We believe that the investigation of *mutual entrainment* can lead to new opportunities and insights in relation to improved human-robot collaboration.

B. Positive Effects of Synchronised Collaboration

While we have characterised different elements of entrainment, an important question yet remains: Why do we want entrainment? We see entrainment not as the goal, but as the method to achieve the goal—synchronisation. Numerous studies have demonstrated that the synchronous behaviour of human collaborators has an abundance of positive side effects. Benefits of synchronous behaviour include amongst others: increased task performance [21], improvement in interpersonal likeability [4], [7] an increased feeling of group behaviour [15], [22], or a sense of togetherness [4].

Miles et al. [9] conducted a study in which people walked in groups next to each other. While people in condition A could see and hear each other, participants in group B were deprived of their situational awareness of others (i.e., they could not see or hear the other participants). This deprivation of awareness, resulted in a lack of entrainment—thereby preventing participants to synchronise their walking patterns—leading to a reduction in trust towards other group members. This was contrasting participants in condition A, who reported higher degrees of trust towards people of their group after synchronised walking.

Valdesolo et al. [21] investigated if being synchronised, not just influences perception, but *improves* performance on specific tasks. Participants completed a joint action coordination task, after being synchronous or asynchronous. They demonstrated being synchronised significantly improved, not just, the sense of similarity and connectedness, but also significantly improved the task completion.

C. Lessons for Effective Human-Robot Entrainment

While studies investigating entrainment between humans and robots are rare (e.g., [8]), lessons for human-robot entrainment can also be achieved through studies investigating human-human entrainment. A recent study by Roy and Edan [17] studied aspects of handovers in short repetitive tasks and provide several recommendations for human-robot collaboration. While their investigation used multiple methods (software simulations, field observations, and recreation in the lab) for data collection, all methods were based purely on human-human interaction. Examples include the recommendation of proactive behaviour for robots, making them able to adapt to human collaborators in order to optimise their behaviour for future interactions, further the *default* collaborative working speed of the robot was identified should optimally match the average human working speed, as well as the need for robots to behave in a socially acceptable way [17].

III. Discussion

We propose a study investigating dyadic and non-dyadic human-human entrainment using tasks resembling typical industrial assembly or packaging tasks. Thereby, we hope to gain insights resulting in a better understanding of how these findings can be transferred to non-dyadic human-robot collaboration in industry.

A. Why non-dyadic Entrainment?

Studying group based entrainment amongst human workers is going to put cobots on the fast track to deployment in industry. In industrial tasks that are short cycle but require human input (e.g. assembly and packaging), a cobot will remove the need for human intervention in aspects of the production cycle, thereby freeing human capital for other tasks. Since cycles are short, it will require to develop ways of collaboration, in which the robot can keep up with the human speed, and vice-versa, while also maintaining safety.

The study proposed below investigates two conditions, the dyadic and the triadic condition. This allows us to investigate if entrainment can be optimised for groups, as well as the potential differences the upscalling of actors can lead to. For instance, we hypothesise, that (H1) the time to synchronise will be proportional to the number of actors, (H2) the increase in actors will strengthen the reliance on explicit communication (e.g., verbal) for entrainment. While two people can exchange information using a single glance, information exchange through direct eye contact requires three glances if the number of actors increases by one (from dyad to triad). The scaling corresponds to

$$|e| = \binom{n}{2} = \frac{n \times (n-1)}{2}, \tag{1}$$

where e = glances, and n = actors.

Furthermore, since collaboration is not limited to dyads there is an increasing trend in a HRC to involve more than two actors. We therefore believe that the investigation of entrainment in non-dyadic settings will enable the HRI community to optimise human-robot collaboration in order to function efficiently, regardless of team sizes.

B. Proposed Studies

This section will briefly present two studies in order to investigate dyadic and non-dyadic entrainment during human-human and human-robot collaboration respectively.

1) Study 1: A Human-Human Investigation of Entrainment: This section describes a mixed-method study, which the authors of this paper, amongst others, are currently designing. The planned study is inspired by Roy et al. [17], who investigated human-human entrainment in a grocery store shelving task to identify design recommendations for entrainment in mixed human-robot teams.

The planned study will contain two tasks requiring temporal and spatial synchronisation between two to three—depending on condition—human participants. Task one resembles a packaging task, for which one participant takes a box and brings it into proximity of the other participants whom each place an object in the box. This task is—provided sufficient materials—infinitely repeatable. The second task requires two/three participants to stamp envelopes in the correct colour. One participant will be responsible for the envelope while the second participant places the stamp—in the triadic setting, the third participant adds a shipping label. For both tasks and conditions, the point-of-assembly is negotiated amongst participants. In order to efficiently complete tasks, i.e., decrease the time needed for each iteration of the task, participants need to align the timing and position of each individual action. More specifically, by aligning temporally and spatially to each other they will be able to reduce the functional delay [3] (i.e., the time they have to wait on one another), making efficient synchronisation a necessity for optimal task completion.

By using both qualitative methods (i.e., questionnaires, post-session interviews, and qualitative video analysis) and quantitative methods (i.e., signal analysis of the pose of each actors hands) we hope to identify synchronisation, reached through entrainment, as well as the cause of this. Thereby identifying contributing mechanisms and metrics to reach efficient synchronisation that can be implemented in a follow up study investigating human-robot collaboration.

2) Study 2: A Human-Robot Investigation of Entrainment: In a second follow up study we plan to model the identified behaviour, and implement it in a collaborative robot (Franka Emika Panda). The study protocol will be based on study 1, but will be replacing one human-participant with the cobot.

As entrainment is the high level goal of this work, we also find it relevant to investigate two additional hypotheses. Just as in the human-human entrainment tasks investigated by Roy et al. [17], our third hypothesis states that (H3) a leader-follower pattern will arise in the human-robot conditions. Furthermore (H4) humans prefer collaborating with robots who change their behaviour, i.e., entrain on the human collaborators, compared to cobots with constant temporal and spatial behaviour, i.e., the robot as a collaborator is preferred over it being just a tool [17]. H4 is motivated by [17] work that recommends that cobot should adapt to the users to personalise their experience.

IV. Conclusion

In this paper we argue for an increased focus on the investigation of entrainment in non-dyadic settings, using tasks resembling an actual context of HRI, the industrial setting. As this is the fastest growing sector for robot adoption, we believe that optimising human-robot collaboration in this sector is of particular importance. We proposed a study design in order to investigate entrainment in human dyads and triads, using tasks resembling industrial tasks such as assembly or packaging. Furthermore, we propose a follow-up study investigating if the identified findings can be transferred to a cobot, and how the they would affect entrainment in mixed human-robot teams.

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