MASTER

Exploring the Relationship between Physiological Synchrony and Team Adaptation

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Exploring the Relationship between Physiological Synchrony and Team Adaptation

Master Thesis

By

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PREFACE

This thesis does not only conclude my master's program Operations Management and Logistics at the Eindhoven University of Technology, it also marks the end of a vibrant and versatile student life. I am grateful for my experiences as a student and, at the same time, I am looking forward to a new chapter in my life.

Without the help of my supervisors, it would not have been possible to complete this thesis and, therefore, I would like to express my gratitude. First of all, I would like to thank my first supervisor, Josette Gevers, for her guidance, feedback and pleasant collaboration throughout the process of writing this thesis. I really appreciate the time and effort you invested in reading my work. I also want to thank my second supervisor, Joyce Westerink, for her efforts and critical, but constructive feedback. It was very useful and I learned a lot from it. Finally, I want to thank Elwira Halgas, who provided me with a lot of great sources and helped me in the right direction at the start of this thesis.

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Ruben Sikkema

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ABSTRACT

In this study, the direct relationship between physiological synchrony and team adaptation was assessed. To that end, both physiological and questionnaire data was gathered from four-person teams performing a collaborative gaming task. The physiological dataset contained cardiovascular and electrodermal signals as well as video recordings of each team member during the task; the questionnaire data contained responses from individual questionnaires, involving questions about the perceived levels of team adaptation. During the gaming task, some teams faced an intervention where an unexpected event was simulated by partially removing one player from the game, thereby stressing the need for team adaptation. Physiological synchrony was computed in the cardiovascular, electrodermal and motor modality by means of three synchrony measures: symbolic entropy, multidimensional recurrence quantification analysis (MdRQA) and coherence. It was investigated how present physiological synchrony was in the current study, how it related to perceived team adaptation, and how the unexpected event influenced levels of team adaptation and physiological synchrony. Results reveal that physiological synchrony in the current study was present above levels expected by chance, but, except for motor synchrony in the coherence measure, did not exceed levels expected for teams composed of non-cooperating persons. No evidence was found for a positive relationship between physiological synchrony and team adaptation. In fact, the symbolic entropy and MdRQA measure reveal that these measures negatively, instead of positively, relate to team adaptation. It should, however, be noted that both of these measures may reflect levels of regularity rather than synchrony in the strict sense and may, therefore, not necessarily capture a relationship between synchrony and team adaptation, but rather a relationship between regularity and team adaptation. The effect of the unexpected event on levels of team adaptation and physiological synchrony was found non-significant in all modalities and measures. In all, results in the current study underline the ambiguity of results in this field of research and show that no definitive patterns have emerged yet.

EXECUTIVE SUMMARY

Introduction & Theoretical Background

The increasingly complex problems and challenges in today's modern world have created a need for more flexible responses and, therefore, the ability to adapt (Kozlowski & Bell, 2003; Volberda, 1996). To address such challenges, organizations typically make use of teams (Weick & Roberts, 1993). The process of adapting within dynamic environments, however, is complex and teams are not necessarily good at it (Driskell et al., 2018; Stachowski et al., 2009). In recognition of this complexity, research has increasingly focused on the concept of team adaptation: *"the change in team performance, in response to a salient cue or cue stream, that leads to a functional outcome for the entire team"* (Burke et al., 2006).

Measurement of team adaptation is difficult. Therefore, research on teamwork has recently increasingly shifted towards novel and more advanced method approaches (Delice et al., 2019). One of such techniques involves the measurement of physiological synchrony: the coordination of physiological signals between two or more individuals. Research has already shown that physiological synchrony can be used as an objective, ongoing and unobtrusive measurement technique for understanding and predicting team functioning and performance (Palumbo et al., 2017), however, it has not been studied in direct relation to team adaptation to this point in time, thereby not utilizing the potential value of this measurement technique in further understanding the concept of team adaptation and its related constructs and processes.

For this reason, the current study was conducted. The aim of this study was to examine the direct relationship between physiological synchrony and team adaptation within four-person teams. To that end, the following main research question was formulated: *"What is the relationship between physiological synchrony and levels of team adaptation within four-person teams?"*. To come up with a comprehensive analysis on this research question, this study assessed physiological synchrony within the following modalities: cardiovascular synchrony, electrodermal synchrony and motor synchrony. For each of the modalities, it was investigated how present they were in the current study, what their relationships were with perceived levels of team adaptation, and how an unexpected event (which stresses the need for team adaptation) affected them.

Method

This study followed an experimental research design. Participants were teamed up in teams of four and asked to complete a collaborative gaming task. During the task, half of the teams were faced with an intervention where one participant could not play the game any longer for a made up reason. Consequently, these teams had to continue playing the game with three members of the team with the fourth member being allowed to give advice (i.e., *experimental condition*), whereas the other teams continued to play the game with four members (i.e., *control condition*).

Data from participants was collected using a combination of wearable physiological sensors, questionnaires, and video recordings. Physiological data from the wearable sensor and video captures was preprocessed and used to compute physiological synchrony in the following measures: symbolic entropy, multidimensional recurrence quantification analysis (MdRQA) and coherence. To this end, multiSyncPy (Hudson et al., 2021) was used. Data from the questionnaires was used to obtain team adaptation scores for each team.

To analyze the presence of physiological synchrony in the current study, two surrogate datasets were created. The first one was obtained by randomly shuffling physiological values across members in a team; the second one was created by randomly swapping participants across teams. The surrogate datasets were used for comparing synchrony scores from the original dataset with the synchrony scores from the surrogate datasets, thereby indicating how physiological synchrony in the current study was different from synchrony levels expected by chance and synchrony levels expected for teams composed of non-cooperating persons.

To analyze the relationship between physiological synchrony and team adaptation, correlation matrices for each modality were obtained by calculating Pearson correlation coefficients between synchrony scores and team adaptation scores.

To examine the effect of the intervention (i.e., the unexpected event) on perceived team adaptation, a Welch’s independent samples t-test was performed for testing the significance of the difference between team adaptation scores from teams in the experimental condition and the team adaptation scores from teams in the control condition. For examining the effect of the intervention on physiological synchrony, two-way ANOVA analyses were conducted on the synchrony scores with one factor being condition (2 levels: control condition and experimental condition) and one factor being level (2 levels: before and after the unexpected event).

Results

Results reveal that physiological synchrony was found significantly higher in the original dataset compared to the first surrogate dataset, indicating that cardiovascular synchrony, electrodermal synchrony and motor synchrony occurred above levels expected by chance.

Except for coherence measure in the motor modality, no statistically significant differences were found between the original dataset and the second dataset, thereby indicating that in most modalities and measures synchrony levels were not higher than expected for teams composed of non-cooperating persons.

Most of the relationships between physiological synchrony in the cardiovascular, electrodermal and motor modalities, and team adaptation were found non-significant. Results that were significant, although not always consistent throughout modalities and conditions, were indicative of a negative relationship between physiological synchrony and team adaptation.

Two-way ANOVA analyses on physiological synchrony measures reveal no statistically significant results for the interaction effects between condition and level, thereby indicating that the unexpected event did not affect levels of physiological synchrony. Moreover, Welch's independent t-test on team adaptation scores reveal no statistically significant differences between the experimental condition and the control condition.

Discussion and Implications

Results reveal that physiological synchrony in the current study was present above levels expected by chance, but, except for motor synchrony in the coherence measure, did not exceed levels expected for teams composed of non-cooperating persons. Following existing literature (Palumbo et al., 2017; Strang et al., 2014), it is argued that these results reflect that physiological study in the current study was the result of conditional similarities, rather than interpersonal dynamics. Measure characteristics might explain why motor synchrony in the current study was found significantly different from motor synchrony in teams composed of non-cooperating persons in the coherence measure, and not in the symbolic entropy and MdRQA measures.

In contrast to what was expected from existing literature, no evidence was found for a positive relationship between physiological synchrony and team adaptation. In fact, the symbolic entropy and MdRQA measure reveal that in some modalities these measures negatively, instead of positively, relate to team adaptation. This shows that results of studies on team adaptation constructs and physiological synchrony cannot simply be extrapolated to the comprehensive relationship between team adaptation and physiological synchrony, and stresses the complexity of the effects of synchrony on team adaptation.

It should be noted that each synchrony measure captures different aspects of synchrony. In fact, both symbolic entropy and MdRQA, when diving deeper into their characteristics, should (potentially) be interpreted as a measure of regularity rather than synchrony in the strict sense. This might explain the found relationships and differences in results among measures in this study, and raises the question whether results on physiological synchrony in existing literature can be generalized when synchrony is computed with different measures. After all, as different measures capture different aspects of synchrony (or even regularity), relationships between team constructs and physiological synchrony can differ with different synchrony measures. Moreover, it stresses how important the role of the chosen synchrony measure is when studying relationships between team constructs and physiological synchrony.

By including an intervention, this study is the first one to investigate the effect of such intervention on levels of physiological synchrony. Although the effect of the intervention in the current study might have been blurred out by other, coinciding, changing variables, this study extends on existing literature by showing that such interventions can be used in the context of physiological synchrony and, as such, it lays a foundation for further research.

Overall, this study serves as another piece in the puzzle of understanding physiological synchrony and its relationship with team constructs. Results underline the ambiguity of this field of research and show that no definitive patterns have emerged yet. By studying physiological synchrony within three different modalities, computed by three different measures, this study contributes to existing literature and lays a foundation for studying physiological synchrony and its relationship with team adaptation more thoroughly.

CONTENTS

LIST OF FIGURES AND TABLES

List of Figures

List of Tables

1 INTRODUCTION

Being able to adapt to shifting environments has played a crucial role during the evolution of life. Organisms with the greatest ability to adapt were the ones with the best chance of survival (Bateson, 2017). This is no different in today's modern world, where adaptation is still a crucial trait for keeping up with changing demands. Technology, for example, is always in a state of change and with developments continually emerging, adaptation is crucial. Organizations face the same need for adaptation as today's hypercompetitive environments require them to be flexible to remain vital (Reeves & Deimler, 2011). Crisis events, too, such as natural disasters or terrorist attacks, require rapid and effective responses to adapt to challenging situations. In general, the increasingly complex problems and challenges in today's modern world have created a need for more flexible responses and, therefore, the ability to adapt (Kozlowski & Bell, 2003; Volberda, 1996).

Living in such era of risk and instability, organizations have acknowledged that they cannot rely on static strategies anymore. Instead of being really good at doing some particular thing, organizations must be really good at learning how to do new things to attain adaptive advantage (Reeves & Deimler, 2011). To that end, organizations typically make use of teams: *"groups of people who are interdependent with respect to information, resources, knowledge and skills and who seek to combine their efforts to achieve a common goal"* (L. L. Thompson, 2004, p. 4). Teams can help organizations to react to acute and unexpected events (Weick & Roberts, 1993) and are, therefore, helpful in addressing complex problems and challenges. Structuring work in this way allows for quick and effective responses within dynamic environments, serving as a key mechanism for adaptation to situational demands (Galbraith, 1993; Mohrman et al., 1995). The process of adapting within dynamic environments, however, is complex and teams are not necessarily good at it (Driskell et al., 2018; Stachowski et al., 2009). In recognition of this complexity, research has increasingly focused on the concept of team adaptation and its related constructs and processes. In this context, team adaptation has been defined as: *"the change in team performance, in response to a salient cue or cue stream, that leads to a functional outcome for the entire team"* (Burke et al., 2006).

Measurement of team adaptation is difficult. That is, traditional measurement techniques for teamwork, such as self-reports or observation-based measures, have shown to suffer from low response rates, response bias, and are obtrusive by interrupting ongoing interactions between team members (Feitosa et al., 2018; Golden et al., 2018; Jones et al., 2013; E. P. Thompson, 1967). Furthermore, asking participants to remember certain experiences involving attitude, behavioral, and cognitive interactions over time is detrimental to the validity of big data (Luciano et al., 2018). In response to these challenges, research on teamwork has recently increasingly shifted towards novel and more advanced method approaches (Delice et al., 2019). One of such techniques involves the measurement of physiological synchrony.

Physiological synchrony refers to the coordination of physiology between two or more individuals and can manifest itself through multiple modalities, including similar heart rate patterns, skin conductance patterns, bodily movements and mimicked facial expressions (e.g., Gordon et al., 2020; Palumbo et al., 2017). These processes operate largely outside of human control and can be measured unobtrusively and objectively by sensors such as wearables. As physiology plays a known role in critical psychosocial processes such as cognition, emotion and behavior, great opportunities arise for studying human behavior more objectively and more unobtrusively than other measurement techniques such as questionnaires or interviews (Kozlowski et al., 2013), thereby being relevant for studying teamwork. Accordingly, research has shown that physiological synchrony can be used as an objective, ongoing and unobtrusive measurement technique for understanding and predicting team functioning and performance (Palumbo et al., 2017). Despite these great benefits, however, physiological synchrony has not been studied in direct relation to team adaptation to this point in time, thereby not utilizing the potential value of this measurement technique in further understanding the concept of team adaptation and its related constructs and processes.

For this reason, the current study is conducted. The aim of this study is to assess the direct relationship between physiological synchrony and team adaptation. To this end, the current study examines synchrony within three different modalities (cardiovascular synchrony, electrodermal synchrony and motor synchrony), and their relationships with team adaptation. Doing this allows for differentiating the modalities and how they relate to the adaptive capacity of teams. Building upon existing literature, it is hypothesized that these relationships are positive in nature. That is, literature has shown that higher levels of synchrony in each of the modalities can be associated with higher levels of constructs underlying team adaptation, such as team situation awareness, team learning and psychological safety (Palumbo et al., 2017), thereby indicating a positive relationship between each modality and team adaptation.

To examine the hypothesized relationships between physiological synchrony and team adaptation, both physiological and questionnaire data was gathered from teams performing a collaborative gaming task. The physiological dataset contains cardiovascular and electrodermal signals as well as video recordings of each team member during the task; the questionnaire data contains responses from individual questionnaires, involving questions about the perceived levels of team adaptation during the gaming task. During the gaming task, some teams faced an intervention where an unexpected event was simulated by partially removing one player from the game, thereby stressing the need for team adaptation. As such, the final sample contains data from two groups: the group that faced an intervention (i.e., experimental condition) and the group that did not face an intervention (i.e., control condition). Multiple synchrony measures were applied to calculate physiological synchrony scores. These scores were subsequently used for testing and analyzing synchrony levels during the gaming task, their relationships with perceived levels of team adaptation, and how the intervention affected the levels of synchrony and perceived team adaptation. Eventually, these results were used to provide comprehensive analyses on the relationship between physiological synchrony and team adaptation.

2 THEORETICAL BACKGROUND

2.1 Physiological Synchrony

When behaving in groups, people tend to coordinate their actions with the people around them (Wiltermuth & Heath, 2009). Such interpersonal synchrony can be observed on a daily basis with people mimicking bodily, vocal or postural actions of others (Decety et al., 2011) such as mimicking facial expressions, synchronized clapping or individuals crossing the same leg when having a seat. Research shows that this synchrony of behavior often occurs without conscious control (Condon & Ogston, 1966) and cannot only be manifested on an observable level, but also on a more fundamental one: the human physiology (e.g., Dimascio et al., 1957; Levenson & Gottman, 1983). The latter phenomenon is also referred to as *physiological synchrony* and has been the subject of a growing field of research (Palumbo et al., 2017).

The big benefit of physiological synchrony for studying teamwork lies in the neuro-scientific principles behind it. Physiological synchrony is the result of interdependence or association in the physiological processes from two or more individuals. Physiological processes such as heart rate, skin conductance or blood pressure, are governed by the Autonomic Nervous System (ANS), in which the Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS) together dynamically regulate internal viscera including cardiac, respiratory and glandular systems (Cacioppo et al., 2007; Palumbo et al., 2017). The ANS is largely outside of conscious control, meaning that humans are not able to consciously control it themselves.

Physiological processes that do not stem from the ANS, such as mimicking facial expressions or synchronizing body movements, can be directed consciously, but often appear to operate outside of conscious awareness as well (Dittmann, 1987; Ramseyer & Tschacher, 2014). As such, physiological processes offer unique potential as objective measures. On top of that, research has shown that physiology plays a known role in critical psychosocial processes such as cognition, emotion and behavior (Cacioppo et al., 2007), which allows it to be studied in the context of teamwork. With this in mind, great opportunities arise to for studying teamwork objectively and unobtrusively by means of underlying physiological processes of team members. In other words, physiological synchrony allows for studying the mind through bodily responses that are (often) not consciously controlled (van Laar, 2019).

As individual physiological processes can provide insights in an individual's state, coordination of these processes across members of a team might provide valuable information about the processes underlying the functioning of the team (Palumbo et al., 2017). As such, research on teamwork and physiological synchrony has proliferated over the last two decades. Henning and colleagues (2001) were the first to study the impact of physiological synchrony between team members on teamwork. Through examining cross-coherence and cross-correlation in respiration, heart rate variability and skin conductance between individuals playing video games, the researchers found that physiological synchrony was a significant predictor of team performance. In the years that followed, research on the topic proliferated with studies focusing on associations between physiological synchrony and other team constructs, such as sympathy (Järvelä et al., 2014; Kaplan et al., 1963; Mitkidis et al., 2015); engagement (Quer, Daftari, and Rao, in press; Marci, 2006); coordination (McFarland, 2001); interpersonal relationships (Field et al., 1992; Goldstein et al., 1989; Müller & Lindenberger, 2011; Silver & Parente, 2004; Strang et al., 2014).

Throughout literature, physiological synchrony has been found in a variety of contexts. Especially teams engaging in gaming tasks show significant levels of physiological synchrony (e.g., Järvelä et al., 2014; Henning et al., 2001; Henning & Korbelak, 2005). More specifically, physiological synchrony seems to occur during tasks that need some form of cooperation, which is in line with a study by Behrens and colleagues (2020). In that study, the researchers examined the relationship between physiological synchrony and cooperation, and showed that physiological synchrony emerges during cooperative contacts. A possible explanation for this phenomenon may be found in a study by Prochazkova and colleagues (2019), who argue that synchronization on the physiological level is associated with the way teammates feel about and behave towards other teammates, which is essential during cooperative tasks. In general, a vast amount of research has shown that physiological synchrony occurs when two or more individuals interact with each other (see Palumbo et al., 2017).

Besides the relationship between physiological synchrony and team concepts, and the context in which synchrony emerges, researchers also became interested in the modalities in which synchrony occurs. Such modalities include cardiovascular (e.g., heart rate, respiratory sinus arrhythmia [RSA], heart rate variability [HRV]), respiratory (e.g., respiratory rate), electrodermal activity (e.g., skin conductance, skin conductance response), thermal (e.g., skin temperature), motor (e.g., motor coordination) and speech (e.g., turn taking, pitch). As each modality has its own characteristics, modalities can differ in what types of team constructs or processes they can capture. Cardiovascular measures, for instance, can be used to asses joint arousal levels or teams' cognitive load (e.g., Dias, 2019), whereas electrodermal activity measures are typically used for capturing interpersonal affection and empathy (see Palumbo et al., 2017). With this in mind, Palumbo and colleagues (2017) conducted a systematic review on physiological synchrony, thereby differentiating between different types of modalities. Although results were not always consistent, the researchers concluded that physiological synchrony in general can be predictive of other variables, such as team performance, empathy or communication. This conclusion is of extreme importance for future research as it embraces the notion that physiological synchrony can be used as a tool for studying team processes and outcomes.

2.2 Physiological Synchrony and Team Adaptation

With the growth of physiological synchrony as a field of research, more and more studies followed on the relationship between physiological synchrony and team constructs, processes and outcomes (see Palumbo, 2017). To this date, however, there has not been a study yet on the direct relation between physiological synchrony and team adaptation, despite team adaptation being an essential characteristic of effective teams (Behling et al., 1967). Nonetheless, this does not mean that such relationship does not exist. Already a lot of research has been conducted on physiological synchrony and team performance (see Palumbo et al., 2017), which is one construct closely related to the outcome of team adaptation. Other studies have, for example, focused on physiological synchrony and coordination or affective ties within teams, of which both have been argued to impact processes of team adaptation. As such, indirect relationships between physiological synchrony and team adaptation have already been investigated. Especially research on cardiovascular synchrony, electrodermal synchrony and motor synchrony show that these modalities can be associated with specific team adaptation constructs and, therefore, team adaptation itself.

2.3 Cardiovascular Synchrony

The cardiovascular system primarily consists of the heart, the blood and the vasculature, and has as primary function to transport oxygen, carbon dioxide, nutrients, waste products and hormones within the body (Humphrey & McCulloch, 2003). The system is highly sensitive to a variety of psychological or physiological conditions, which can manifest themselves in simple ways, such as increased heart rate during physical activities, or in more complex processes, such as a correlation between levels of empathy and cardiac activity (Oliveira-Silva & Gonçalves, 2011). As a result, the cardiovascular system can be suitable for capturing an individual's psychological or physiological state.

Cardiovascular synchrony has been found in a variety of interpersonal contexts. Dimascio and colleagues (1955), for example, showed shared co-variation in heart rate between patient and psycho-therapist. Levenson and Gottman (1983) found high levels of physiological synchrony, including heart rate, in couples during therapy. Other studies found similar effects for studies involving romantic couples (Helm et al., 2012), choir singers (Müller & Lindenberger, 2011) and fire-walking rituals (Konvalinka et al., 2011). Studies such as these show initial evidence for a relationship between cardiovascular synchrony and interpersonal dynamics. Many of these studies, however, have focused on dyads (see Palumbo et al., 2017), whereas team interactions are more complex and, therefore, require different coordination assessment methods (Amon et al., 2019; Moreland, 2010).

Although literature on cardiovascular synchrony in groups or teams consisting of three or more individuals has increased over the last decade, research on the topic is still scarce. Moreover, some findings in this field of research have not been consistently supported over the years. A study on physiological synchrony measures including HRV within teams (Henning et al., 2009), for instance, found negative correlations between these measures and team members' ratings of team productivity, quality of communication, and ability to work together, thereby indicating low ratings of team performance. At the same time, Elkins and colleagues (2009), conversely, found positive correlations between cardiovascular synchrony and team performance in a military setting. The contradictive results illustrate the complexity of this field of research and are indicative of the maturing process the field is in.

The ambiguous results make it difficult to draw relationships between cardiovascular synchrony and team adaptation from existing literature. Research on constructs underlying team adaptation and their relationships with cardiovascular synchrony, however, does provide some insights.

A first insight in the relationship between cardiovascular synchrony and team adaptation can be found in the relationships between cardiovascular synchrony and team performance. Although team adaptation and team performance are two different constructs, it is argued that high levels of team adaptation are associated with high levels of team performance (e.g., Burke et al., 2006; Christian et al., 2017; Maynard et al., 2015). In other words, adaptive teams have the capacity to perform better than non-adaptive teams. From a physiological point of view, teams high in performance have been positively associated with levels of cardiovascular synchrony (Elkins et al., 2009). When also including research within dyads, evidence for such relationship becomes even more prevalent (e.g., Henning & Korbelak, 2005; Henning et al., 2001; Montague et al., 2014; Walker et al., 2013). Researchers, therefore, suggested that a positive relationship between cardiovascular synchrony and team performance does indeed exist (see Palumbo et al., 2017), despite some studies not supporting this notion (e.g., van Laar, 2019). As such, both team adaptation and cardiovascular synchrony can be indicative of the performance of teams.

In contrast to adaptive teams, there is little known about the underlying reasons for cardiovascular synchronized teams to perform so well. Some researchers suggest that this could be dependent of the situation (Gordon et al., 2020), whereas others are more explicit in their conclusions. Gil and Henning (2000), for instance, conducted a study in which seventeen two-person teams of undergraduates performed a computer-based, simulated teleoperation task. The results of the study suggest that cardiovascular synchrony reflects increased team situation awareness, intra-team coordination and shared mental models, enhancing the performance of the teams. Recently, studies by Gordon and colleagues (2020) and Filho and colleagues (2017) indirectly found evidence for this claim by linking cardiovascular synchrony, respectively, to team coordination and shared mental models. Specifically, Gordon and colleagues (2020) found that the consequences of cardiovascular synchronization during a drumming task contribute to coordination within three-person teams, whereas Filho and colleagues (2017) linked increased cardiovascular synchrony between professional jugglers during a juggling task with several coordination mechanisms underlying the concept of shared mental models. As team situation awareness, intra-team coordination and shared mental models are known to be important processes underlying effective team adaptation (Burke et al., 2006), one can argue that cardiovascular synchrony may very well represent an indicator and/or predictor of team adaptation.

A secondary insight in the relationship between cardiovascular synchrony and team adaptation can be found in how cardiovascular synchrony relates to interpersonal relationships. Gordon and colleagues (2020), for instance, found that cardiovascular synchrony is predictive of individuals' experience of group cohesion, suggesting that it contributes to group bonds. Research within dyads shows that trust has an effect on cardiovascular synchrony, such that increased cardiovascular synchrony could be a marker of the trust building process within teams (Mitkidis et al., 2015). More generally, being in a social, familiar or romantic relationship may catalyze cardiovascular synchrony (Chatel-Goldman et al., 2014; Helm et al., 2012; Konvalinka et al., 2011; Levenson & Gottman, 1983). Affection, trust and perceived group cohesion are also of importance for adaptive teams. That is, Burke and colleagues (2006) argued that team adaptation can benefit from high levels of psychological safety, the definition of which shows significant overlap with affection, trust and group cohesion. As such, higher levels of cardiovascular synchrony may represent higher levels of psychological safety and, therefore, it may indicate higher team adaptation.

Finally, at least two studies have shown that increased cardiovascular synchrony can be associated with handling unexpected events. Henning and Korbelak (2005) studied team performance of two-person teams performing a self-paced projective tracking task under laboratory conditions. During the task, unexpected changes in task control dynamics occurred randomly. The results of the study indicate that cardiovascular synchrony has potential for assessing a team's readiness to handle unexpected task demands in the immediate future. The second study focused on the relationship between cardiovascular synchrony and team cognitive load within three-person operating room teams (Dias et al., 2019). The researchers concluded that cardiovascular synchrony rapidly increased when a patient was at risk, for example after a near-miss medication event, eventually resulting in positive surgery outcomes. These two studies suggest a positive relationship between cardiovascular synchrony within teams and handling unexpected events, and by doing so, they have indicated a relationship between cardiovascular synchrony and team adaptation in the most direct way.

In all, research on constructs underlying team adaptation and their relationships with cardiovascular synchrony provide some indications that team adaptation is positively related to cardiovascular synchrony. A rationale for this relationship may be found in the underlying mechanisms of cardiovascular synchrony. That is, a widely embraced notion is that individuals are likely to increasingly synchronize heart rate dynamics when their behaviors are coordinated and when they share emotional ground (Fusaroli et al., 2016). For team adaptation constructs, such as team situation awareness, team coordination, shared mental models and psychological safety, this is crucial. In addition, it is inherent to these constructs that team members are behaviorally and emotionally well aligned and coordinated, thereby 'consequently' having synchronized heart rate dynamics among team members. As such, cardiovascular synchrony might indeed represent constructs inherent to team adaptation and, therefore, team adaptation itself.

2.4 Electrodermal Synchrony

Electrodermal activity (EDA) refers to a measure of the electrical conductance of the skin (Posada-Quintero et al., 2018). EDA is the product of innervation of sweat glands that results in changing levels of sweat in the ducts, leading to variations in EDA levels (Edelberg, 1993). As this mechanism is controlled by the sympathetic nervous system, skin conductance can be considered as an indication of psychological or physiological arousal (Martini et al., 2012). That is, if the sympathetic nervous system is highly aroused, then sweat gland activity also increases, eventually resulting in increased levels of skin conductance. Throughout literature, EDA has not only been associated with central mechanisms such as gross movements, thermoregulatory sweating and fine control, but also with affective processes, orientation and attention (Edelberg, 1973; Hugdahl, 2001; Boucsein, 2012), and, therefore, researchers argued that skin conductance can be a measure of emotional and sympathetic responses (Carlson, 2013).

Like research on cardiovascular synchrony, literature on electrodermal synchrony within groups of three or more individuals is scarce. That is, researchers started studying the topic only half a decade ago with the aim of extending literature on electrodermal synchrony within dyads to larger collectives (e.g., Guastello et al., 2016). Since then, research on electrodermal synchrony in groups of three or more individuals increased, however, results are ambiguous. For instance, studies investigating the relationship between electrodermal synchrony and team performance have found non-significant (Dindar, Järvelä, et al., 2020) and negative effects (Guastello et al., 2016) as well as team performance leading to increased synchrony (Guastello et al., 2018). With regards to group cohesion, electrodermal synchrony has been found to both correlate with team satisfaction (Guastello et al., 2019), and group tension and negative affect (Mønster et al., 2016). Such findings are in line with research on electrodermal synchrony within dyads, whose ambiguity has been discussed in a systematic review by Palumbo and colleagues (2017). In all, the contradicting results show that no definitive patterns have emerged yet in this field of research.

Due to its ambiguity, it is hard drawing relations from existing literature on electrodermal synchrony, especially within the context of team adaptation. Not all results, however, are conflicting. In fact, several studies do provide insights in the relationship between electrodermal synchrony and team adaptation. More specifically, research suggests a positive effect of electrodermal synchrony on team adaptation by means of team learning. Burke and colleagues (2006) argued that team learning is part of the process of team adaptation, facilitating the development of knowledge and contributing to the ability of members to improve their collective understanding of a given situation. As such, high levels of team learning are expected to contribute to high levels of team adaptive performance. Research on team learning and electrodermal synchrony has shown positive relationships between the two constructs. That is, Pijeira Dìaz and colleagues (2016) have found that electrodermal synchrony can be a predictor of collaborative learning. Similarly, Haataja and colleagues (2018) and Dindar and colleagues (2020) showed that electrodermal synchrony occurred during collaborative learning processes. To this date, there are no studies that contradict these results. As such, research on electrodermal synchrony and team learning indicate a positive relationship between the two constructs, from which it follows that team adaptation may be linked to electrodermal synchronization in teams.

2.5 Motor Synchrony

In the context of this study, motor synchrony refers to the synchronization of bodily movements of individuals, such as crossing the same leg when seated or synchronized facial expressions. Motor synchrony is different from cardiovascular and electrodermal synchrony in that it does not stem from the Autonomic Nervous System. Nevertheless, similar to cardiovascular and electrodermal synchrony, motor synchrony often appear to occur without conscious control (Condon & Ogston, 1966; Ramseyer & Tschacher, 2014), which enables it to be an objective measure of interpersonal synchrony.

Motor synchrony among members of a species is common in nature. Think, for example, of mosquitos synchronizing their wing flaps during mating (Cator et al., 2009) or fishes living in schools (Katz et al., 2011). Humans are no different to this, showing synchrony spanning group sizes and across different forms of behavior when interacting with others (McNeill, 1995), including synchronized body movements (Paxton & Dale, 2013a, 2013b; Schmidt et al., 2012), eye movements (D. C. Richardson et al., 2007) or expressive emotion (Main et al., 2016). Such synchrony, as well as its underlying constructs, has increasingly interested researchers over the years. Although the functional role of motor synchrony is not entirely clear, many researchers point towards group cohesion and interpersonal affect as two of the main drivers (e.g., Fujiwara et al., 2020; Jermann & Nüssli, 2012; Miles et al., 2011; Mønster et al., 2016; Paxton & Dale, 2013a).

Numerous studies have established a link between motor synchrony and group cohesion or interpersonal affect. Studies within dyads, for example, found positive relationships between motor synchrony and affiliation (Paxton & Dale, 2013a), mutual understanding (Jermann & Nüssli, 2012; D. C. Richardson et al., 2007; D. C. Richardson & Dale, 2005), interpersonal cooperation (Van Baaren et al., 2004; Wiltermuth & Heath, 2009) and the desire to bridge a social gap when there was a perceived or potential breakdown in interaction (Fujiwara et al., 2020; Miles et al., 2011; M. J. Richardson et al., 2012). Research on motor synchrony within groups of three or more individuals echoes a similar notion. Mønster and colleagues (2016), for example, concluded that synchrony of smiling was positively related to team cohesion and positive affect towards team members in a study where teams of three people built origami boats together in an assembly-line manner while their facial muscle activity was recorded. Similarly, Codrons and colleagues (2014) studied arm movements at rest and during spontaneous, music and metronome-associated arm-swinging within collective and individual groups, where the participants were given no directions on whether or how the arm swinging were to be synchronized. The researchers found higher levels of motor synchrony in collective groups compared to individual groups. In general, motor synchrony has been found to create feelings of trust and closeness between people (Butler as seen in Baer, 2017).

In the context of motor synchrony, researchers argue that feelings of trust and closeness between people are caused by *self-other blurring:* a weakening of boundaries between self and other. That is, as individuals become attuned to other people's actions, whether they do it consciously or not, they integrate them with their own (Konvalinka as seen in Zaraska, 2020). This results in increased levels of affinity, eventually leading to increased collaboration and performance (Chang et al., 2017).

As motor synchrony is associated with feelings of trust and closeness, it is likely that motor synchrony is also associated with team adaptation, given that such affective processes are important for team adaptation by enhancing levels psychological safety (Burke et al., 2006). With this in mind, one could argue that motor synchronized teams display higher levels of team adaptation, which implicates that the two may be positively related.

2.6 Unexpected Events

The most direct way for teams to display team adaptation is when they are faced with unexpected events. Unexpected events can manifest themselves in multiple ways, such as the loss of a team member, failure of resources or sudden changes in task demands. Effectively coping with such events is difficult and require teams to be flexible (Stachowski et al., 2009). Moreover, adapting to situational changes is complex as all sorts of team constructs, such as coordination, shared mental models and psychological safety, play a role in this process (Thommes, 2021). As a result, teams are not necessarily good at handling unexpected events and adjusting to situational demands (Stachowski et al., 2009).

Existing literature provide a lot of evidence for the latter notion. Membership loss for example, is associated with weaker transactive memory systems (Akgün et al., 2005) and less developed shared mental models (Bedwell, 2012), eventually resulting in decreased team adaptive performance (Bedwell, 2012, 2019). External threats make teams become more rigid and narrow-focused (Staw et al., 1981), eventually leading to restricted information sharing, less group discussion and reduced coordination (Kamphuis et al., 2011), which is detrimental for effectively handling unexpected events (De Dreu & West, 2001; Srivastava et al., 2006; Thommes, 2021). Changes in task demands require modifications in team interactions and emergent states, which teams are less likely to overcome when the magnitude of the change is high (Thommes, 2021). In general, unexpected events influence team effectiveness and the more disruptive the unexpected event is, the harder it is for teams to develop effective adaptive responses (Thommes, 2021).

Following the above, it is likely that an unexpected event also influences physiological synchrony. After all, as discussed in the previous sections, higher levels of physiological synchrony can be associated with higher levels of team adaptation, and vice versa. As such, the effect of an disruptive unexpected event on team adaptation may be reflected in lower levels of physiological synchrony. Following this rationale, it is likely that there exists a relationship between unexpected events, team adaptation and physiological synchrony, in such way that more disruptive events are associated with lower levels of team adaptation and physiological synchrony.

3 RESEARCH AIM AND QUESTIONS

3.1 Aim of the Current Study

Physiological synchrony shows great potential as an objective and unobtrusive measurement technique for studying teamwork (Palumbo et al., 2017). Although research on physiological synchrony has increased over the years, still no research has been conducted on the direct relationship between physiological synchrony and team adaptation, despite the importance of team adaptation in today's modern world. At the same time, existing literature on physiological synchrony shows that it can be associated with team processes and team states underlying team adaptation, especially in the cardiovascular, electrodermal and motor modalities. As such, indirect relationships between team adaptation and physiological synchrony have already been investigated. It remains, however, unclear how team adaptation itself relates to physiological synchrony. The current study, therefore, aims to fill this research gap by examining the direct relationship between physiological synchrony and team adaptation. In addition, the effect of an unexpected event on physiological synchrony and team adaptation is studied as unexpected events stress the need for team adaptation, thereby allowing for further investigation of the relationship between team adaptation and physiological synchrony. Physiological synchrony is studied within four-person teams playing a collaborative online game.

3.2 Research Questions

The primary aim of this study is to investigate the relationship between physiological synchrony and team adaptation. Therefore, the main research question is:

- **RQ:** What is the relationship between physiological synchrony and levels of team adaptation within four-person teams?

To answer the main research question, this study assesses synchrony within three modalities: cardiovascular synchrony, electrodermal synchrony and motor synchrony[1]. As it is not given up front that synchrony occurs within these modalities during this study, the following sub questions arise:

[1] For the context of this study, motor patterns were considered as physiological signals.

- **RQ 1.1:** Does cardiovascular synchrony occur during collaborative online game play in four-person teams?
- **RQ 1.2:** Does electrodermal synchrony occur during collaborative online game play in four-person teams?
- **RQ 1.3:** Does motor synchrony occur during collaborative online game play in four-person teams?

To assess the relationship between physiological synchrony in each of the modalities and team adaptation, the following research questions are formulated:

- **RQ 2.1:** How does cardiovascular synchrony relate to team adaptation during collaborative online game play in four-person teams?
- **RQ 2.2:** How does electrodermal synchrony relate to team adaptation during collaborative online game play in four-person teams?
- **RQ 2.3:** How does motor synchrony relate to team adaptation during collaborative online game play in four-person teams?

In the current study, some teams will face an intervention where an unexpected event is simulated, thereby stressing the need for team adaptation. To examine the effect of this unexpected event on levels of team adaptation and physiological synchrony, the following research questions are formulated:

- **RQ 3.1:** How does an unexpected event influence team adaptation during collaborative game play in a four-person team?
- **RQ 3.2:** How does an unexpected event influence cardiovascular synchrony during collaborative game play in a four-person team?
- **RQ 3.3:** How does an unexpected event influence electrodermal synchrony during collaborative game play in a four-person team?
- **RQ 3.4:** How does an unexpected event influence motor synchrony during collaborative game play in a four-person team?

4 HYPOTHESES

Building upon existing literature as discussed in the *theoretical background*, this section aims to construct hypotheses on the research questions as formulated in the previous section.

4.1 Occurrence of Physiological Synchrony

In the *theoretical background* section it was shown that physiological synchrony occurs within a variety of situations, especially in those where cooperative contacts are crucial. For this reason, the following hypotheses regarding the occurrence of physiological synchrony in the experiment of the current study, in which participants needed to cooperate, are proposed:

Hypothesis 1.1: Cardiovascular synchrony occurs during collaborative game play in a four-person team

Hypothesis 1.2: Electrodermal synchrony occurs during collaborative game play in a four-person team

Hypothesis 1.3: Motor synchrony occurs during collaborative game play in a four-person team

4.2 Relationship Cardiovascular Synchrony and Perceived Team Adaptation

Earlier, it was discussed that cardiovascular synchrony can be positively associated with team adaptation constructs such as team situation awareness, team coordination, shared mental models, handling unexpected events and psychological safety (see *theoretical background*). As such, cardiovascular synchrony might represent constructs inherent to team adaptation and, therefore, team adaptation itself. With this in mind, the following hypothesis is proposed:

Hypothesis 2.1: Cardiovascular synchrony relates positively to perceived team adaptation

4.3 Relationship Electrodermal Synchrony and Perceived Team Adaptation

As described in the *theoretical background* section, electrodermal synchrony is positively associated with team learning throughout existing literature. Given that team learning is crucial to the process of team adaptation (Burke et al., 2006), thereby facilitating the development of knowledge and contributing to the ability of members to improve their collective understanding of a given situation, electrodermal synchrony may be closely related to team adaptation itself. Therefore, the following hypothesis is proposed:

Hypothesis 2.2: Electrodermal synchrony relates positively to perceived team adaptation

4.4 Relationship Motor Synchrony and Perceived Team Adaptation

Throughout existing literature, numerous of studies have established a link between motor synchrony and group cohesion or interpersonal affect, which is argued to be the result of *self-other blurring* (see *theoretical background*). As feelings of trust and closeness also play an important role in team adaptation, one can argue that motor synchrony is potentially positively related to psychological safety and, therefore, team adaptation itself. In that context, the following hypothesis is proposed:

Hypothesis 2.3: Motor synchrony relates positively to perceived team adaptation

4.5 Effect of an Unexpected Event

In the *theoretical background* section is was discussed how a disruptive unexpected event can have a negative effect on team adaptation. Building upon the other hypotheses in this section, where it was argued that physiological synchrony reflects team adaptation constructs and, therefore, team adaptation itself, this also means that such unexpected event will lead to decreased levels of physiological synchrony. After all, higher levels of physiological synchrony are associated with higher levels of team adaptation, and vice versa. Following this rationale, the following hypotheses are proposed:

Hypothesis 3.1: An unexpected event will negatively affect perceived team adaptation

Hypothesis 3.2: An unexpected event will negatively affect cardiovascular synchrony

Hypothesis 3.3: An unexpected event will negatively affect electrodermal synchrony

Hypothesis 3.4: An unexpected event will negatively affect motor synchrony

5 METHOD

5.1 Research Design

This study followed an experimental, naturalistic research design. Participants were teamed up in teams of four and asked to complete a collaborative gaming task. The research approach is naturalistic in the sense that it allowed variation in interaction patterns to occur between participants during the experiment. That is, participants were allowed to interact freely within the constraints placed upon them for completing the given gaming task. The experiments were held within Mindlabs facilities, where data was collected using a combination of wearable physiological sensors, questionnaires, and audio/video recording.

The collaborative game that was played in the experiment is called *'Lovers in a Dangerous Spacetime'*. The game is a space shooter video game, which can be played alone or with two to four players. During the game, players pilot a spaceship with a variety of stations located inside it, including the ship's weapons, engine, shield, cannon, and map. The goal of the game is to rescue an assortment of captured creatures, which is hindered by attacking enemies. As such, players must constantly move from station to station in order to balance flying the ship and protect it from damage and attacking enemies. Game performance is measured by the amount of saved creatures and the time it took to do so.

The game was played in four levels: one trial level and three regular levels, ascending in difficulty. Physiological synchrony was computed on the physiological data from the second and the third regular levels in the game. These are the last two levels of the experiment, thereby being the two levels with the highest difficulty. As such, teams really needed to work together and adapt to the changing demands of the game. As these are the last two levels of the experiment, it was also assumed that participants had developed a good understanding of the game during the preceding levels.

After the second level in the game, half of the teams were faced with an intervention where one participant could not play the game any longer for a made up reason. Consequently, these teams had to continue playing the game with three members of the team with the fourth member being allowed to give advice (i.e., *experimental condition*), whereas the other teams continued to play the game with four members (i.e., *control condition*).

5.2 Research Procedure

Participants were recruited through TiU's SONA system. Prior to the experiment, participants were provided with general information about the purpose of the experiment, the procedure during the experiment, safety measures, clothing restrictions, and data storage. Participants were also provided with an informed consent before the start of the experiment, which they were asked to read carefully and sign afterwards.

Recruited participants were seated behind a computer screen at the start of the experiment, after which they were instructed by the researcher to put on the Shimmer GSR+ sensor and a headset. The researcher asked each participant to raise a fist with the arm on which the Shimmer GSR+ sensor is attached, which was needed for alignment of the data. Before the start of the actual game, participants were asked to fill in a questionnaire containing questions on biographical data and gaming experience. After completing this questionnaire, participants were provided with a PowerPoint presentation on the gameplay and basic mechanics of the game. The presentation was followed by a short test on the knowledge of the game of the participants.

After completion of the short test on the knowledge of the game, the actual game was played, where teams in the experimental condition faced the intervention (see *research design*) after the second regular level, whereas teams in the control condition did not. After completion of the third level, all participants were asked to fill in a questionnaire with multiple measures, including the perceived level of team adaptation during the game. After this, the participants were debriefed and the experiment was completed.

5.3 Participants

The criteria for participation included being between 18 and 67 years old, and not having used recreational drugs, coffee, caffeine-containing tea or cigarettes for 5 hours prior to the experiment. The collaborative gaming task was completed by 45 teams of four, with 22 teams in the experimental condition and 23 teams in the control condition. Table 1 shows the biographical details of the participants.

Participation was rewarded with course credit and a €15 gift card incentive for each member of the team with the best score during the collaborative gaming task, €10 gift card each for the second best team and €5 gift card each for the third best team.

Table 1

Biographical details of participants

Condition	Gender	Occurrence	Fraction (%)	M age	SD age
Experimental	Male	46	52.27	21.00	2.66
	Female	42	47.73	21.19	2.51
	Other	0	0	-	-
	Total	***88***	***100***	***21.09***	***2.54***
Control	Male	46	50.00	21.17	3.14
	Female	45	48.91	21.38	3.14
	Other	1	1.09	20	0
	Total	***92***	***100***	***21.26***	***3.13***
Whole dataset	Male	92	51.11	21.09	2.91
	Female	87	48.33	21.29	2.86
	Other	1	.06	20	0
	Total	***180***	***100***	***21.18***	***2.88***

5.4 Measures

5.4.1 Biographical Questionnaire

A questionnaire was provided at the start of the experiment to collect information regarding participants' age, gender, program of study, nationality, usage of recreational drugs/coffee/nicotine containing substances in the last five hours before the start of the experiment, experience with dealing with crisis situations, relationship with the other participants and gaming experience.

5.4.2 Team Adaptation Questionnaire

At the end of the experiment, participants were asked to fill in a questionnaire with multiple measures, including a block of eight questions to measure their perceived team adaptation. These questions were introduced by Marques-Quinteiro and colleagues in 2015 as an instrument for measuring team adaptive performance. The questions were: *"We find innovative ways to deal with unexpected events"*; *"We use creative ideas to manage incoming events"*; *"We devise alternative plans in very short time, as a way to cope with new task demands"*: *"We adjust and deal with unpredictable situations by shifting focus and taking reasonable action"*; *"Periodically, we update technical and interpersonal competences as a way to better perform the tasks in which we are enrolled"*; *"We search and develop new competences to deal with difficult situations"*; *"We remain calm and behave positively under highly stressful events"* and *"We maintain focus when dealing with multiple situations and responsibilities"*. Participants were asked to rate these questions on a 7-point scale ranging from 1 (totally ineffective) to 7 (totally effective), as described by Marques-Quinteiro and colleagues (2015). The Cronbach's alpha of this questionnaire in the current study was .854, indicating good internal consistency (Gliem & Gliem, 2003). Cronbach's alpha was computed in SPSS Statistics 27.

5.4.3 Physiological Data Measurement

During the entire duration of the experiment, participants were equipped with a Shimmer GSR+ sensor, which measured several things, including heart rate activity and skin conductance. Webcams on top of the computer screens were used for capturing facial video recordings of the participants during the experiment.

5.4.4 Physiological Synchrony Measures

Physiological synchrony was computed in three modalities: the cardiovascular modality, the electrodermal modality and the motor modality. For the cardiovascular modality, heart rate signals from the Shimmer were used; for the electrodermal modality, EDA signals from the Shimmer were used; for the motor modality, facial video recordings of the participants were used.

For computing physiological synchrony, multiSyncPy (Hudson et al., 2021) was used. MultiSyncPy is a Python package for quantifying multivariate synchrony, offering functions to calculate several different synchrony measures. It also includes functions for two surrogation techniques to compare the observed coordination dynamics with chance levels. MultiSyncPy takes time series as input and calculates the average synchrony among time series in specific synchrony measures. With multiSyncPy, the following synchrony measures were computed: *symbolic entropy*, *multidimensional recurrence quantification* and *coherence*.

Symbolic entropy examines the entropy of system states over time. Each data point in the data stream of each participant was mapped to a value of either 'low', 'medium' or 'high' at each time step, based on the terciles of the data stream. The conjunction of these mapped values represented an element in a symbol set that characterized the overall collective system state for any given point in time. For a four-person team in this study, at a certain point in time, this could for example be: 'high-high-low-medium'. The entropy of system states (Shannon, 1997) was then calculated in multiSyncPy over 60 seconds time windows, with a time step of 1 second. Mathematical details on calculating entropy can be found in Shannon (1997). The eventual output of the symbolic entropy measure was the average entropy score over all time windows. Note that symbolic entropy reflects whether behavior of team members is synchronized around some shared pattern. In other words, when the signals of all team members go up and down in synchrony over time, a low entropy is obtained.

Multidimensional recurrence quantification (mdRQA) is a recurrence-based analysis technique that is based on the repetition of the same or similar values between time series. It has become a prominent technique for calculating interdependence among physiological signals of individuals doing collaborative work (Dindar, Järvelä, et al., 2020). In multiSyncPy, MdRQA was computed by means of a binary recurrence matrix, which indicated which points in time were similar to which other points in time between multiple signals (Coco et al., 2020). The similarity of two points in time was determined by the Euclidean distance, on which a radius threshold was applied. Hereby, the threshold provided a binary classification, with states being either recurrent or not. The binary classifications together formed a square matrix, where the column and the row index both specified points in time (i.e., the times being compared). As such, the main diagonal represented a comparison of the system to itself without any time delay, and so was always populated entirely with ones, while diagonals close to the main diagonal represented a comparison of the system to itself with a short delay. The recurrence matrix was used to compute the proportion of recurrence (%REC), which is the number of recurrent cells divided by the total number of cells. As such, the %REC measure reflects to what extent the signals of all team members combined show similar patterns throughout time. Note that higher recurrence indicates that a team exhibits a specific behavior to a higher extent over time. Mathematical details on MdRQA can be found in Wallot et al. (2016)

Coherence is based on spectral analysis of data signals and indicates how well one signal can be approximated by a linear function of the other signal (White, 1984), thereby being similar to cross-correlation. The difference between coherence and cross-correlation, however, is that coherence translates time series into the frequency domain by means of the Fourier transformation. The idea behind this is that a time series signal is composed of multiple sine waves of different frequencies and can therefore be described by means of the power at each of these frequencies, which is referred to as the power spectrum of the time series. Coherence was computed for each pair in a team (i.e., in total six pairs of participants in the four-person teams in this study) by assessing the normalized correlation between power spectra of the time series of each pair, resulting in a measure ranging from 0 to 1, with higher values indicating higher coherence among signals. Following a method introduced by Reinero and colleagues (2021), these pair-wise coherence scores were then averaged across the group, providing a team-level coherence measure for synchrony. Mathematical details and sensitivity analysis for the coherence measure can be found in Winterhalder et al. (2006).

Although results are often very similar (Guevara & Corsi-Cabrera, 1996), the advantage of coherence compared to cross-correlation is that coherence is not subject to exact time points, thereby allowing for ‘lag’ between signals as long as the signals have a stable similarity (Guevara & Corsi-Cabrera, 1996). As such, the coherence measure of synchrony reflects to what extent the signals of the team members fluctuate with similar frequencies, with higher values implying higher levels of synchrony.

5.5 Data preprocessing

5.5.1 Data Alignment

Before actual analysis, data was aligned. Alignment was needed as not all measuring devices started recording at the exact same time. As such, time differences arose among data streams. Alignment started with the facial video recordings. In Adobe Audition, each of the facial video recordings was aligned to the exact start of the game, for which a video capture of the gameplay was used as a guideline. Thereafter, data streams from the Shimmer sensor (i.e., cardiac and electrodermal activity) were aligned to the video captures: this alignment was done in Python and performed on the point in time where participants raised their fist, a movement that is clearly visible in both Shimmer data and facial video captures. Once all the data streams were aligned, subsets were created for each level in the game.

5.5.2 Heart Rate Data Preprocessing

Heart rate data was obtained from the PPG Shimmer signals. That is, after applying a Butterworth lowpass filter with a cutoff value of 3.38 Hz (de Cheveigné & Nelken, 2019), the PPG signals were windowed into 30s windows with a 1s sliding window. These windows were used for translating the PPG signals to HR signals (with BPM as unit). Note that the resulting HR signals have a sampling frequency of 1 Hz as a result of the 1s sliding window. The HR signals were checked for missing data and for artifacts by detection of fast edges, similar to an approach by Westerink and colleagues (2020). That is, edges increasing or decreasing faster than 10 BPM per second were flagged. For ±3s windows around the flagged edges, BPM values were replaced by means of linear interpolation. Missing data was replaced by means of mean interpolation. All preprocessing steps were performed in Python.

5.5.3 EDA Data Preprocessing

For EDA signal preprocessing, skin conductance (SC) data from the Shimmer was used. First, a Butterworth lowpass filter with a cutoff frequency of 10 Hz was applied (de Cheveigné & Nelken, 2019) to SC data from the Shimmer signals. These signals were down sampled to 10 Hz, after which they were checked for artifacts by detection of fast edges, similar to Westerink and colleagues (2020). Edges increasing faster than 7.5% of SC level per second, or decreasing faster 1% of SC level per second were flagged. For ±500ms windows around the flagged edges, SC values were replaced by means of linear interpolation. Then, a moving average filter at 0.1 Hz was applied for further noise removal. Finally, the SC signals were translated to phasic EDA signals by means of the PyPhysio library (Bizzego et al., 2019). All preprocessing steps were performed in Python.

5.5.4 Video Recording Preprocessing

To analyze the video captures of each participant, the OpenFace 2.0 toolkit was used (Baltrusaitis et al., 2018). OpenFace 2.0 is a state of the art tool for facial action unit recognition, gaze estimation, facial landmark detection, and head pose estimation. As such, video recordings can be translated into quantitative data streams. For this study, facial action unit recognition was used for calculation of motor synchrony. Facial action unit recognition is based on the Facial Action Coding System (FACS), which is a system to taxonomize human facial movements by their appearance on the face. The system was originally developed by Hjortsjö (1969), and later on adopted and further developed by Ekman and colleagues (2002). As the FACS breaks down facial expressions into individual components of muscle movement (Action Units [AUs]), it allows for studying specific emotion related facial expressions.

For this study, the following facial expressions were extracted for studying motor synchrony: *happiness*, *sadness*, *surprise*, *fear*, *anger* and *contempt*. To that end, OpenFace 2.0 was used to extract AU1, AU2, AU4, AU5, AU6, AU7, AU12, AU14, AU15, AU20, AU23 and AU26 from the facial video recordings as different combinations of these AUs represent the facial expressions of interest (see *Facial Action Coding System (FACS) - A Visual Guidebook* (n.d.)). The software detected in each frame of the videos, sampled at 30 Hz, the intensity (from 0 to 5, continuous) of each of the selected AUs, thereby indicating the intensity of presence with 0 being not present, 1 being present at minimum intensity and 5 being present at maximum intensity. Frames where OpenFace 2.0 had less than 85% confidence in the landmark detection were replaced by means of mean interpolation. Eventually, the AUs were combined into specific combinations representing the facial expressions of interest, thereby resulting in quantified facial expression data streams for the respective emotions.

5.5.5 Data Trimming

Recordings can be of different lengths. Therefore, to perform analyses on a dataset with greater consistency, data was trimmed, similar to an approach used by Hudson and colleagues (2021). That is, data points were taken from the middle of each level for all teams and modalities corresponding to the fastest time it took any team to complete any of the second or third level (i.e., the levels of interest for this study, see *Research design*). This time was equal to 2 minutes and 22 seconds and, therefore, data was trimmed 1 minute and 11 seconds before the middle and 1 minute and 11 seconds after the middle. Note that, as modalities had different sampling frequencies, the amount of data points taken differed among modalities. It was chosen to trim data from the middle of each level as most of the action during the game happened in the middle of a level. At those moments, participants really needed to work together and adapt to the changing demands of the game, which should have had the most impact on physiological synchrony.

5.5.6 Creating Surrogate Data

The first research question centers around presence of physiological synchrony. To investigate its significance, two surrogate datasets were created, similar to studies by Hudson and colleagues (2021) and Strang and colleagues (2014). The first one was obtained by randomly shuffling physiological values across members in a team (surrogate dataset 1); the second one was created by randomly swapping participants across teams (surrogate dataset 2). The surrogate datasets were used for comparing synchrony scores from the original dataset with the synchrony scores from the surrogate datasets, which will later be elaborated on in the *data analysis* subsection.

5.5.7 Obtaining MdRQA Parameter Sets

To capture the proper dynamics of time series using MdRQA, it was needed to estimate a delay parameter *d*, an embedding parameter *m*, and a threshold parameter *r*. To that end, multivariate parameter estimation methods (Wallot & Mønster, 2018) were used, where *d* was estimated as the first local minimum of an average mutual information function of the time series, *m* was estimated as the first local minimum of a multidimensional false-nearest-neighbor function and *r* was chosen such that the average %REC in a dataset was approximately 5%–10%. As dynamics differ among the two surrogate datasets, and frequencies differ among modalities, it was not possible to obtain a single set of parameters that yield the desired average %REC of approximately 5%–10% (see *Measures*) for all datasets and modalities. Therefore, multiple sets of parameters were used, which allowed for comparing %REC values between original data and each of the surrogate datasets, but not for comparing between modalities (Wallot & Leonardi, 2018). Parameter sets were selected so that parameter values for delay and embedding dimension were somewhat above the average of the dataset, because recurrence-based analyses are robust against (moderate degrees) of over-embedding (Webber Jr & Zbilut, 2005). Table 2 shows an overview of the selected parameter sets.

Table 2

Overview of MdRQA parameter sets

Comparison dataset	Modality	d	m	r
Real – Surrogate dataset 1:	Cardiovascular	5	6	4.4
(MdRQA parameter set 1)	Electrodermal	2	3	1.4
	Motor	8	3	2.1
Real – Surrogate dataset 2:	Cardiovascular	8	6	2.3
(MdRQA parameter set 2)	Electrodermal	3	3	1.6
	Motor	15	3	1.9

5.6 Data Analysis

For the analyses, physiological data from participants was used. Recording devices, however, did not always capture data correctly and, therefore, data from some teams had to be discarded. Table 3 shows the number of correctly captured teams in each modality.

For each team, for each modality, physiological synchrony was obtained in the symbolic entropy measure, the MdRQA measure and the coherence measure in both the second and the third regular level. Figure 1 depicts this process for a given team in a given level. Note that motor synchrony includes an extra step in this process to translate AU data streams to facial expression data streams (see *video recording preprocessing*). The obtained synchrony scores were used to answer the research questions.

Table 3

Correctly captured teams in each modality

Modality	Whole dataset	Experimental condition	Control condition
Cardiovascular	28	15	13
Electrodermal	37	19	18
Motor	34	16	18

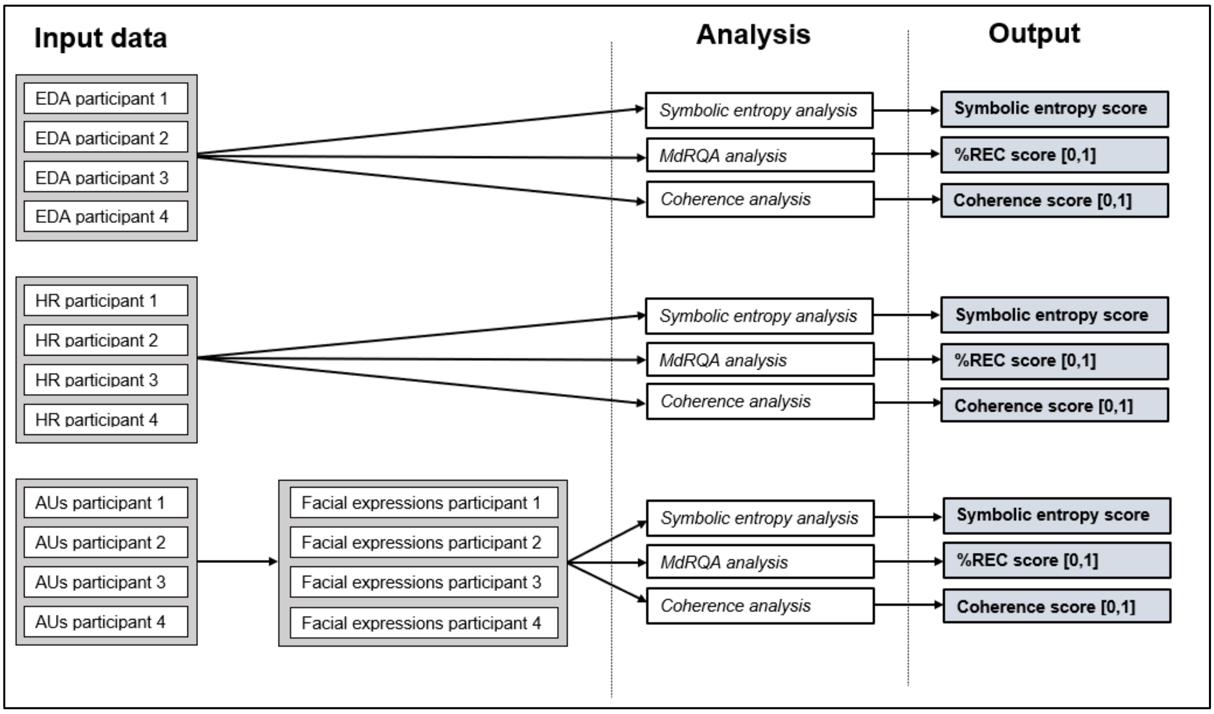

Figure 1: the process of computing physiological synchrony in a level for any given team

5.6.1 Presence of Physiological Synchrony **[Research Question 1]**

For each level, significance of the physiological synchrony scores was tested. To that end, the two surrogate datasets were created, as described in the *creating surrogate data* subsection. The surrogate datasets were used for recomputing the synchrony measures, which were compared to the scores obtained by the original data streams. The Welch's independent samples t-test was used for testing the significance of the difference between synchrony scores in the original dataset and synchrony scores in the two surrogate datasets. Here, comparing with synchrony scores in the first surrogate dataset allowed for investigating whether the levels of synchrony occurred above the levels expected by chance, while comparing with synchrony scores in the second surrogate dataset allowed for investigating whether the levels of synchrony occurred above the levels expected in a team working on the same task, but with no interactions between team members. The differences in synchrony between the original data streams and the surrogate datasets were tested for significance at the .05 (two-tailed) level. Also, results were subjected to a Bonferroni adjustment for the fact that three tests are performed in each level, lowering the significance level to 0.0167 (two-tailed). Finally, Cohen's d values were computed to account for effect sizes. Effect sizes were interpretated as small ($d = 0.2$), medium ($d = 0.5$) or large ($d = 0.8$) (Cohen, 1988).

5.6.2 Relationship between Physiological Synchrony and Team Adaptation **[Research Question 2]**

To examine the direct relationship between physiological synchrony and team adaptation, synchrony scores from the second and the third level in the game, and team adaptation scores from the questionnaire were used. Correlation matrices for each modality were obtained by calculating Pearson correlation coefficients between synchrony scores and team adaptation scores. The correlation coefficients were calculated for the whole sample, the control condition only and the experimental condition only. Correlations with the modalities in the MdRQA measure were computed on MdRQA scores obtained with MdRQA parameter set 2 (see *Obtaining MdRQA parameter sets*) as this parameter set captures the dynamics of the original dataset better than the MdRQA parameter set 1. All correlation coefficients were tested for significance at the .05 and .01 level (two-tailed).

5.6.3 Effect of the Unexpected Event **[Research question 3]**

To examine the effect of the intervention (i.e., the unexpected event) on perceived team adaptation, a Welch's independent samples t-test was performed for testing the significance of the difference between team adaptation scores from teams in the experimental condition and the team adaptation scores from teams in the control condition. This difference was tested for significance at the .05 (two-tailed) level.

To examine the effect of the intervention (i.e., the unexpected event) on physiological synchrony, a two-way ANOVA was conducted on the synchrony scores with one factor being condition (2 levels: control condition and experimental condition) and one factor being level (2 levels: before and after the unexpected event). Here, the main effect of condition indicated whether there was more (or less) synchrony in the experimental than in the control condition; the main effect of level indicated whether synchrony changed from going from the second level to the third level; and the interaction effect between level and condition indicated whether the change in synchrony from the second level to the third level did or did not depend on the condition (i.e., the effect of the intervention). Each of the effects were tested for significance at the .05 level (two-tailed).

6 RESULTS

Tables 4 and 5 present overviews of means (*M*), standard deviations (*SD*) and pair-wise Pearson correlations of the variables in this study for the second level and the third level in the game, respectively. Many associations were intuitive (e.g., between different measures for the same modality), yet others were intriguing (e.g., negative correlations between synchrony measures and team adaptation scores). In this section, most of the associations will be investigated and discussed in more detail.

6.1 Presence of Physiological Synchrony

For the first research question it was of interest if physiological synchrony indeed occurred during the experiment. To that end, synchrony scores from the original data were compared with two surrogate datasets: a dataset obtained by randomly shuffling values across members in a team (surrogate dataset 1), and a dataset obtained by randomly swapping participants across teams (surrogate dataset 2). Three measures were computed: symbolic entropy, MdRQA and coherence. Lower values for symbolic entropy are considered indicative of synchrony, while for the coherence and MdRQA measure higher values are considered indicative of synchrony. The results are organized into three subsections: one for cardiovascular synchrony, one for electrodermal synchrony, and one for motor synchrony.

Table 4

Descriptives and correlations for level 2

Variable	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. SE cardiovascular	2.827	.210	1																								
2. SE electrodermal	4.231	.028	.07	1																							
3. SE happiness	2.506	.596	.31	-.12	1																						
4. SE sadness	3.752	.330	-.20	-.08	.07	1																					
5. SE surprise	3.762	.236	.19	.14	.44**	.43*	1																				
6. SE fear	4.166	.066	-.05	-.23	-.24	.12	.14	1																			
7. SE anger	3.972	.248	.20	-.04	.48**	.46*	.57**	.09	1																		
8. SE contempt	3.412	.491	-.02	-.06	.29	.38*	.17	-.07	.19	1																	
9. MdRQA cardiovascular	7.06	2.23	-.72**	.01	.04	.14	-.14	-.13	.11	.00	1																
10. MdRQA electrodermal	8.37	5.34	.11	-.24	-.04	.07	.19	.32	.04	-.26	-.09	1															
11. MdRQA happiness	24.21	12.68	.02	.07	-.09	-.05	-.04	-.43*	-.30	.15	-.29	-.29	1														
12. MdRQA sadness	5.91	4.26	.18	.00	.16	-.59**	-.23	-.24	-.27	-.41*	-.25	-.07	.25	1													
13. MdRQA surprise	8.39	4.92	-.08	.05	.00	-.31	-.37*	-.35*	-.35*	-.19	-.16	-.13	.34*	.79**	1												
14. MdRQA fear	3.60	3.23	.01	.00	-.04	-.32	-.41*	-.42*	-.46**	-.32	-.21	-.05	.35*	.76**	.84**	1											
15. MdRQA anger	3.11	2.66	-.03	-.03	-.17	-.47**	-.30	-.21	-.69**	-.40*	-.21	.06	.40*	.65**	.64**	.80**	1										
16. MdRQA contempt	12.63	7.68	.03	.20	.04	-.25	-.02	-.31	-.28	-.44**	-.22	.05	.57**	.61**	.55**	.68**	.69**	1									
17. Coh. cardiovascular	.194	.027	-.27	-.03	-.02	.12	.02	-.04	-.08	.07	.32	.17	-.32	-.01	.05	.15	.09	-.16	1								
18. Coh. electrodermal	.104	.007	-.03	.29	.06	-.06	.28	.02	.25	-.26	-.04	.21	.00	.18	.20	.16	.12	.27	.11	1							
19. Coh. happiness	.045	.011	.09	.01	-.20	-.27	-.34*	-.15	-.21	-.32	-.14	-.07	.38*	.13	.11	.17	.28	.47**	-.39	.01	1						
20. Coh. sadness	.038	.007	.34	-.15	-.02	-.37*	-.23	-.09	-.08	-.15	-.27	-.07	.10	.52**	.44**	.34	.33	.13	-.07	.18	.16	1					
21. Coh. surprise	.038	.008	.39	.03	-.05	-.26	-.15	-.27	.00	-.03	-.26	-.18	.09	.37*	.35*	.21	.14	.02	.02	.14	.11	.89**	1				
22. Coh. fear	.037	.006	.19	.08	.07	-.37*	-.12	-.27	-.14	-.17	-.14	-.13	.13	.67**	.61**	.56**	.50**	.33	.18	.26	.06	.82**	.75**	1			
23. Coh. anger	.036	.004	.06	.06	-.18	-.35*	-.21	-.21	-.26	-.39*	-.18	-.08	.30	.48**	.50**	.54**	.60**	.46**	-.06	.33	.30	.60**	.44*	.73**	1		
24. Coh. contempt	.038	.005	.05	.39*	.01	-.26	-.05	-.27	-.05	-.37*	-.13	-.24	.27	.30	.15	.31	.30	.64**	-.18	.19	.68**	-.05	-.01	.15	.29	1	
25. Team adaptation	40.57	4.08	-.12	.01	-.04	.24	.45**	.23	.27	.09	-.03	.12	-.01	-.27	-.31	-.42*	-.36*	.12	-.03	-.07	-.04	-.15	-.12	-.18	-.31	-.09	1

Note 1: SE = Symbolic entropy; Coh. = Coherence

Note 2: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 5

Descriptives and correlations for level 3

Variable	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. SE cardiovascular	2.870	.149	1																								
2. SE electrodermal	4.219	.028	-.08	1																							
3. SE happiness	2.218	.584	-.17	-.23	1																						
4. SE sadness	3.714	.362	-.06	.16	.13	1																					
5. SE surprise	3.825	.227	-.31	.20	.09	**.54****	1																				
6. SE fear	4.164	.073	-.16	-.12	-.12	.07	**.42***	1																			
7. SE anger	3.854	.266	-.33	-.13	.24	**.53****	**.34***	.22	1																		
8. SE contempt	3.402	.469	-.33	-.01	.33	-.16	-.10	.03	-.07	1																	
9. MdRQA cardiovascular	6.50	2.45	-.34	-.17	.27	.18	.14	.11	.25	.18	1																
10. MdRQA electrodermal	10.16	5.25	.24	**-.37***	.12	-.10	-.22	-.08	-.08	-.06	.18	1															
11. MdRQA happiness	26.52	13.06	.20	.08	-.33	.01	-.16	**-.43***	-.26	-.12	-.10	.21	1														
12. MdRQA sadness	6.59	6.27	.03	-.14	-.01	**-.56****	**-.43***	-.25	**-.52****	.04	-.16	.09	-.04	1													
13. MdRQA surprise	9.56	5.26	-.03	-.15	-.03	**-.50****	-.33	-.18	**-.36***	.07	-.06	-.08	-.06	**.88****	1												
14. MdRQA fear	4.14	3.59	.04	-.04	.00	**-.50****	-.34	-.25	**-.45****	.08	-.01	.07	-.04	**.89****	**.84****	1											
15. MdRQA anger	5.18	4.49	.09	.15	-.05	**-.55****	**-.45****	**-.37***	**-.68****	.09	-.24	.04	.16	**.77****	**.72****	**.82****	1										
16. MdRQA contempt	12.22	8.88	.20	.08	-.13	.17	-.03	-.21	.02	**-.56****	.06	.06	**.58****	.05	.08	.07	.09	1									
17. Coh. cardiovascular	.18	.024	-.03	-.38	**.43***	-.30	.06	.03	.11	.20	.06	.19	-.22	.19	.18	.22	.04	.02	1								
18. Coh. electrodermal	.108	.008	-.10	-.11	-.32	.01	.13	.13	-.02	.01	.10	.28	-.13	.02	.03	.04	-.01	-.24	.27	1							
19. Coh. happiness	.044	.014	-.12	.23	-.23	-.02	-.26	-.17	-.19	-.01	.42*	.17	**.43***	-.03	-.06	.04	.18	**.41***	-.11	-.19	1						
20. Coh. sadness	.036	.007	.24	-.21	.07	-.27	**-.52****	-.31	-.13	.26	.05	.08	-.03	.29	.19	.14	.19	-.11	.23	-.12	.31	1					
21. Coh. surprise	.036	.006	.28	-.16	.01	-.23	**-.53****	**-.45****	-.04	.17	.19	.00	.06	.32	.23	.26	.20	-.02	.26	-.10	.25	**.87****	1				
22. Coh. fear	.036	.005	.21	-.09	.00	**-.46****	**-.51****	**-.40***	-.26	.25	.26	-.04	-.06	**.42***	**.34***	**.36***	**.37***	-.15	.27	-.12	.29	**.83****	**.86****	1			
23. Coh. anger	.036	.006	.06	.08	-.10	**-.36***	**-.39***	**-.40***	-.32	.10	.03	-.10	.01	**.49****	**.44****	**.53****	**.60****	-.05	.03	-.13	**.44***	**.68****	**.64****	**.77****	1		
24. Coh. contempt	.036	.006	.14	.04	-.18	.07	-.23	-.16	-.02	-.16	.35	.21	**.41***	-.07	-.06	.02	.07	**.49****	-.12	-.16	**.86****	**.38***	.34	.30	**.45****	1	
25. Team adaptation	40.57	4.08	.02	.17	-.18	.03	.14	.17	.07	.01	**-.41***	-.31	-.10	-.15	-.08	-.16	.02	.00	-.31	-.19	.16	.16	.02	.08	.15	.20	1

Note 1: SE = Symbolic entropy; Coh. = Coherence

Note 2: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

6.1.1 Cardiovascular Synchrony ***[Research Question 1.1]***

Table 6 and table 7 report the results of Welch's independent samples t-tests for comparing cardiovascular synchrony scores from the original dataset with the cardiovascular synchrony scores from surrogate dataset 1 and surrogate dataset 2, respectively. It was hypothesized that cardiovascular synchrony would occur during the experiment.

Table 6 reveals that, except for the coherence measure in the third level ($t(46) = 1.947$, $p = .058$), synchrony scores are significantly higher in the original dataset compared to surrogate dataset 1 (at the .05 level, two-tailed). These results remain significant after applying a Bonferroni adjustment. Furthermore, for both levels, effect sizes are considered large for the symbolic entropy and MdRQA measures ($d > |.8|$); for the coherence measure in the second level the effect size is considered medium ($d = .704$). This indicates that cardiovascular synchrony occurred above the levels expected by chance for the symbolic entropy and MdRQA measure in both levels and for the coherence measure in the second level.

Table 7 reveals that only for the coherence measure in the second level, cardiovascular synchrony was significantly higher in the original dataset compared to the surrogate dataset 2 ($t(54) = 2.013$, $p = .049$, *Cohen's* $d = .538$). However, after applying a Bonferroni adjustment, this difference does not remain significant. As such, the results indicate that teams composed of persons that were actually cooperating did not have levels of cardiovascular synchrony above those expected for teams composed of non-cooperating persons performing the same task.

In all, significant evidence was found that cardiovascular synchrony occurred above levels expected by chance. Results from comparing with surrogate dataset 2, however, reveal that these levels are not higher than expected for teams composed of non-cooperating persons performing the same task. As such, this boils down to the following: cardiovascular synchrony occurred during the experiment, but not at levels exceeding teams composed of random, non-cooperating persons. Although this leaves room for discussion, the results, in essence, confirm hypothesis 1.1. That is, cardiovascular synchrony did occur during the experiment.

Table 6										
Overview results cardiovascular synchrony compared to surrogate dataset 1										
Level	Measure	n	M	SD	M (surrogate)	SD (surrogate)	df	t	p	Cohen's d
L2	Symbolic entropy	28	2.827	.210	3.700	.036	29	-21.686	**< .001**	-5.796
	Coherence	28	.194	.027	.179	.014	40	2.635	**.012**	.704
	MDRQA (%REC)	28	20.30	4.25	.33	.22	27	24.849	**< .001**	6.641
L3	Symbolic entropy	28	2.870	.149	3.708	.033	30	-29.069	**< .001**	-7.769
	Coherence	28	.183	.024	.173	.015	46	1.947	.058	.520
	MDRQA (%REC)	28	19.97	8.20	.43	.45	27	12.596	**< .001**	3.366

Table 7										
Overview results cardiovascular synchrony compared to surrogate dataset 2										
Level	Measure	n	M	SD	M (surrogate)	SD (surrogate)	df	t	p	Cohen's d
L2	Symbolic entropy	28	2.827	.210	2.880	.150	49	-1.089	.282	-.291
	Coherence	28	.194	.027	.180	.025	54	2.013	.049	.538
	MDRQA (%REC)	28	7.06	2.23	6.58	1.51	46	.901	.372	.241
L3	Symbolic entropy	28	2.870	.149	2.901	.133	53	-.809	.422	-.216
	Coherence	28	.183	.024	.179	.021	53	.667	.508	.178
	MDRQA (%REC)	28	6.50	2.45	6.03	2.25	54	.751	.456	.201

6.1.2 Electrodermal Synchrony ***[Research Question 1.2]***

Table 8 and table 9 report the results of Welch's independent samples t-tests for comparing electrodermal synchrony scores from the original dataset with the cardiovascular synchrony scores from surrogate dataset 1 and surrogate dataset 2, respectively. It was hypothesized that electrodermal synchrony would occur during the experiment.

Table 8 reveals that electrodermal synchrony was significantly higher in the original dataset compared to the surrogate dataset 1 in the symbolic entropy measure in both levels (*Level 2: t(41) = -20.984, p < .001, Cohen's d = -4.879; Level 3: t(41) = -24.526, p < .001, Cohen's d = -5.702*), and the coherence and MdRQA measure in the third level (*Coherence: t(63) = 2.580, p = .012, Cohen's d = .600; MdRQA: t(67) = 4.357, p < .001, Cohen's d = 1.013*). These results remain significant after applying a Bonferroni adjustment. No significant differences were found for the coherence and MdRQA measure in the second level. Effect sizes are considered large for the symbolic entropy measure in both levels and for the MdRQA measure in the third level (*d* > |*.8*|). The effect size for the coherence measure in the third level is considered medium (*d = 0.6*). As such, the results indicate that electrodermal synchrony occurred above the levels expected by chance for the symbolic entropy measure in both levels, and for the coherence measure and MdRQA measure in the third level.

Table 9 reveal that only for the MdRQA measure in the second level, electrodermal synchrony was significantly higher in the original dataset compared to the surrogate dataset (*t(72) = 2.256, p = .027, Cohen's d = .568*). However, after applying a Bonferroni adjustment, this difference does not remain significant. As such, the results indicate that teams composed of persons that were actually cooperating did not have levels of electrodermal synchrony above those expected for teams composed of non-cooperating persons performing the same task.

In all, significant evidence was found that electrodermal synchrony occurred above levels expected by chance. Results from comparing with surrogate dataset 2, however, reveal that these levels are not higher than expected for teams composed of non-cooperating persons performing the same task. As such, this boils down to the following: electrodermal synchrony occurred during the experiment, but not at levels exceeding teams composed of random, non-cooperating persons. Although this leaves room for discussion, the results, in essence, confirm hypothesis 1.2. That is, electrodermal synchrony did occur during the experiment.

Table 8

Overview results electrodermal synchrony compared to surrogate dataset 1

Level	Measure	n	M	SD	M (surrogate)	SD (surrogate)	df	t	p	Cohen's d
L2	Symbolic entropy	37	4.231	.028	4.331	.007	41	-20.984	< **.001**	-4.879
	Coherence	37	.104	.007	.103	.005	68	.734	.465	.171
	MDRQA (%REC)	37	7.18	4.54	6.32	5.09	71	.771	.443	.179
L3	Symbolic entropy	37	4.219	.028	4.334	.007	41	-24.526	< **.001**	-5.702
	Coherence	37	.108	.008	.104	.005	63	2.58	**.012**	.600
	MDRQA (%REC)	37	8.91	4.63	4.73	3.54	67	4.357	< **.001**	1.013

Table 9

Overview results electrodermal synchrony compared to surrogate dataset 2

Level	Measure	n	M	SD	M (surrogate)	SD (surrogate)	df	t	p	Cohen's d
L2	Symbolic entropy	37	4.231	.028	4.222	.026	72	1.326	.189	.308
	Coherence	37	.104	.007	.106	.009	66	-1.462	.148	-3.40
	MDRQA (%REC)	37	8.37	5.34	5.51	5.59	72	2.256	.027	.568
L3	Symbolic entropy	37	4.219	.028	4.211	.035	68	1.049	.298	.244
	Coherence	37	.108	.008	.109	.013	60	-.397	.693	-.092
	MDRQA (%REC)	37	10.16	5.25	7.77	6.78	68	1.699	.094	.395

6.1.3 Motor Synchrony ***[Research Question 1.3]***

Table 10 and table 11 report the results of Welch's independent samples t-tests for comparing motor synchrony scores from the original dataset with the cardiovascular synchrony scores from surrogate dataset 1 and surrogate dataset 2, respectively. As described in the *method* section, motor synchrony is decomposed into six facial expressions: *happiness, sadness, surprise, fear, anger* and *contempt*. It was hypothesized that motor synchrony would occur during the experiment.

Happiness. The results in table 10 reveal that motor synchrony in the happiness facial expression is significantly higher compared to the surrogate dataset 1 at the 0.05 level (two-tailed) for all measures in both levels. Only for the symbolic entropy measure in the third level, the result does not remain significant after applying a Bonferroni adjustment ($t(58) = -2.207, p = .031$). Effect sizes are considered large for all measures that remained significant after applying the Bonferroni adjustment ($d > |.8|$). As such, the results indicate that motor synchrony in the happiness facial expression did occur above the levels expected by chance, except for synchrony in the symbolic entropy measure in the third level.

The results in table 11 reveal that motor synchrony in the happiness facial expression is only significantly higher compared to the surrogate dataset 2 at the 0.05 level (two-tailed) for the coherence measure in both levels (*Level 2:* $t(51) = 5.138, p < .001$, *Cohen's* $d = 1.246$*; Level 3:* $t(44) = 3.762, p < .001$, *Cohen's* $d = .912$). These results remain significant after applying a Bonferroni adjustment. Results for the other measures in both levels are not significant. Effect sizes are considered large for the coherence measure in both levels ($d > |.8|$). As such, the results indicate that teams composed of persons that were actually cooperating did only have levels of motor synchrony in the happiness facial expression above those expected for teams composed of non-cooperating persons performing the same task in the coherence measure.

Sadness. The results in table 10 reveal that motor synchrony in the sadness facial expression is significantly higher compared to the surrogate dataset 1 at the 0.05 level (two-tailed) for all measures in both levels. Only for the coherence measure in the third level, the result does not remain significant after applying a Bonferroni adjustment ($t(35) = 2.369, p = .023$). Effect sizes are considered large for all measures that remained significant after applying the Bonferroni adjustment ($d > |.8|$). As such, the results indicate that motor synchrony in the sadness facial expression did occur above the levels expected by chance, except for synchrony in the coherence measure in the third level.

The results in table 11 reveal that motor synchrony in the sadness facial expression is only significantly higher compared to the surrogate dataset 2 at the 0.05 level (two-tailed) for the coherence measure in the second level (*t(39) = 3.210, p = .003, Cohen's d = .779*). This result remains significant after applying a Bonferroni adjustment. All other results for motor synchrony in the sadness facial expression are not significant. The effect size of the coherence measure in the second level is considered medium (*d = .779*). As such, the results indicate that teams composed of persons that were actually cooperating did only have levels of motor synchrony in the sadness facial expression above those expected for teams composed of non-cooperating persons performing the same task in the coherence measure in the second level.

Surprise. The results in table 10 reveal that motor synchrony in the surprise facial expression is significantly higher compared to the surrogate dataset 1 at the 0.05 level (two-tailed) for all measures in both levels. These results remain significant after applying a Bonferroni adjustment. The effect size for the coherence measure in the third level is considered medium (*d = .630)*, whereas effect sizes of all other measures are considered large (*d* > |*.8*|). As such, the results indicate that motor synchrony in the surprise facial expression did occur above the levels expected by chance.

The results in table 11 reveal that motor synchrony in the surprise facial expression is only significantly higher compared to the surrogate dataset 2 at the 0.05 level (two-tailed) for the coherence measure in both levels (*Level 2: t(34) = 3.120, p = .003, Cohen's d = .757; Level 3: t(44) = 2.564, p = .014, Cohen's d = .622*). These results remain significant after applying a Bonferroni adjustment for the fact that three tests are performed in each level. Results for the other measures in both levels are not significant. Effect sizes are considered medium for the coherence measure in both levels (*Level 2: d = .757; Level 3: d = .622)*. As such, the results indicate that teams composed of persons that were actually cooperating did only have levels of motor synchrony in the surprise facial expression above those expected for teams composed of non-cooperating persons performing the same task in the coherence measure.

Fear. The results in table 10 reveal that motor synchrony in the fear facial expression is significantly higher compared to the surrogate dataset 1 at the .05 level (two-tailed) for all measures in both levels. These results remain significant after applying a Bonferroni adjustment. The effect size for the coherence measure in the third level is considered medium (*d = .637)*, whereas effect sizes of all other measures are considered large (*d* > |*.8*|). As such, the results indicate that motor synchrony in the fear facial expression did occur above the levels expected by chance.

The results in table 11 reveal that motor synchrony in the fear facial expression is only significantly higher compared to the surrogate dataset 2 at the .05 level (two-tailed) for the coherence measure in both levels (*Level 2: t(45) = 3.429, p = .001, Cohen's d = .832; Level 3: t(45) = 2.606, p = .012, Cohen's d = .632*). These results remain significant after applying a Bonferroni adjustment. Results for the other measures in both levels are not significant. Effect sizes are considered large for the coherence measure in the second level (*d* = *.832*), and medium in the third level (*d* = *.632*). As such, the results indicate that teams composed of persons that were actually cooperating did only have levels of motor synchrony in the fear facial expression above those expected for teams composed of non-cooperating persons performing the same task in the coherence measure.

Anger. The results in table 10 reveal that motor synchrony in the anger facial expression is significantly higher compared to the surrogate dataset 1 at the .05 level (two-tailed) for all measures in both levels. These results remain significant after applying a Bonferroni adjustment. The effect size for the coherence measure in the third level is considered medium (*d* = *.724*), whereas effect sizes of all other measures are considered large (*d* > |*.8*|). As such, the results indicate that motor synchrony in the anger facial expression did occur above the levels expected by chance.

The results in table 11 reveal that motor synchrony in the anger facial expression is only significantly higher compared to the surrogate dataset 2 at the .05 level (two-tailed) for the coherence measure in both levels (*Level 2: t(48) = 2.461, p = .018, Cohen's d = .597; Level 3: t(54) = 2.741, p = .008, Cohen's d = .665*). These results remain significant for the third level, but not for the second level, after applying a Bonferroni adjustment for the fact that three tests are performed in each level. Results for the other measures in both levels are not significant. The effect size for the coherence measure in the third level is considered medium (*d* = *.665*). As such, the results indicate that teams composed of persons that were actually cooperating did only have levels of motor synchrony in the anger facial expression above those expected for teams composed of non-cooperating persons performing the same task in the coherence measure in the third level.

Contempt. The results in table 10 reveal that motor synchrony in the contempt facial expression is significantly higher compared to the surrogate dataset 1 at the .05 level (two-tailed) for all measures in both levels. These results remain significant after applying a Bonferroni adjustment. The effect size for the coherence measure in the third level is considered medium (*d = .794*), whereas effect sizes of all other measures are considered large (*d* > |*.8*|). As such, the results indicate that motor synchrony in the contempt facial expression did occur above the levels expected by chance.

The results in table 11 reveal that motor synchrony in the contempt facial expression is only significantly higher compared to the surrogate dataset 2 at the .05 level (two-tailed) for the coherence measure in both levels (*Level 2: t(54) = 3.641, p = .001, Cohen's d = .883; Level 3: t(51) = 2.537, p = .014, Cohen's d = .615*). These results remain significant after applying a Bonferroni adjustment. Results for the other measures in both levels are not significant. Effect sizes are considered large for the coherence measure in the second level (*d = .883*), and medium in the third level (*d = .615*). As such, the results indicate that teams composed of persons that were actually cooperating did only have levels of motor synchrony in the contempt facial expression above those expected for teams composed of non-cooperating persons performing the same task in the coherence measure.

Combining the results. In all, although results slightly differ among facial expressions, they are generally similar. That is, in all facial expressions, significant evidence was found that motor synchrony occurred above levels expected by chance. Results from comparing with surrogate dataset 2 reveal that these levels, all together, are higher than expected for teams composed of non-cooperating persons performing the same task in the coherence measure, but not in the symbolic entropy measure and MdRQA measure. As such, this boils down to the following: motor synchrony occurred during the experiment, sometimes even above levels expected for teams composed of random, non-cooperating persons as indicated by the coherence measure. Although it leaves room for discussion why the latter result is not supported by the symbolic entropy measure and MdRQA measure, the results, in essence, confirm hypothesis 1.3. That is, motor synchrony did occur during the experiment.

Table 10

Overview results motor synchrony compared to surrogate dataset 1

Level	Emotion	Measure	n	M	SD	M (sur)	SD (sur)	df	t	p	Cohen's d
L2	Happiness	Symbolic entropy	34	2.506	.596	3.161	.885	58	-3.579	**.001**	-.868
		Coherence	34	.045	.011	.033	.001	30	5.586	< **.001**	1.462
		MDRQA (%REC)	34	29.95	13.86	8.15	9.19	57	7.643	< **.001**	1.854
	Sadness	Symbolic entropy	34	3.752	.330	4.634	.052	35	-10.682	< **.001**	-2.591
		Coherence	34	.038	.007	.033	.001	31	3.793	**.001**	.919
		MDRQA (%REC)	34	9.96	5.67	1.65	1.42	37	8.286	< **.001**	2.010
	Surprise	Symbolic entropy	34	3.762	.236	4.354	.120	49	-13.015	< **.001**	-3.157
		Coherence	34	.038	.008	.033	.002	35	3.800	**.001**	.922
		MDRQA (%REC)	34	13.23	5.91	2.93	2.17	42	9.539	< **.001**	2.313
	Fear	Symbolic entropy	34	4.166	.066	4.374	.002	33	-18.439	< **.001**	-4.472
		Coherence	34	.037	.006	.033	.001	36	3.502	**.001**	.849
		MDRQA (%REC)	34	6.63	4.35	.69	.63	34	7.873	< **.001**	1.910
	Anger	Symbolic entropy	34	3.972	.248	4.374	.002	33	-9.446	< **.001**	-2.291
		Coherence	34	.036	.004	.033	.001	39	3.526	**.001**	.855
		MDRQA (%REC)	34	6.01	3.85	.95	1.37	41	7.220	< **.001**	1.751
	Contempt	Symbolic entropy	34	3.412	.491	4.211	.525	66	-6.484	< **.001**	-1.573
		Coherence	34	.038	.005	.033	.001	37	4.334	< **.001**	1.051
		MDRQA (%REC)	34	18.33	8.30	.92	.98	34	12.142	< **.001**	2.945
L3	Happiness	Symbolic entropy	34	2.218	.584	2.617	.876	58	-2.207	.031	-.535
		Coherence	34	.044	.014	.033	.001	34	4.629	< **.001**	1.123
		MDRQA (%REC)	34	32.25	13.65	6.23	4.98	42	10.442	< **.001**	2.533
	Sadness	Symbolic entropy	34	3.714	.362	4.237	.455	63	-5.248	< **.001**	-1.273
		Coherence	34	.036	.007	.033	.001	35	2.369	.023	.574
		MDRQA (%REC)	34	10.81	7.77	4.42	6.41	64	3.698	< **.001**	.897
	Surprise	Symbolic entropy	34	3.825	.227	4.373	.002	33	-14.039	< **.001**	-3.405
		Coherence	34	.036	.006	.033	.002	37	2.599	**.013**	.630
		MDRQA (%REC)	34	14.67	6.05	6.68	6.76	65	5.135	< **.001**	1.245
	Fear	Symbolic entropy	34	4.164	.073	4.374	.002	33	-16.763	< **.001**	-4.066
		Coherence	34	.036	.005	.033	.001	36	2.626	**.013**	.637
		MDRQA (%REC)	34	7.56	5.04	2.14	4.18	60	5.091	< **.001**	1.235
	Anger	Symbolic entropy	34	3.854	.266	4.284	.373	60	-5.483	< **.001**	-1.330
		Coherence	34	.036	.006	.033	.001	36	2.987	**.005**	.724
		MDRQA (%REC)	34	9.03	6.09	2.31	4.11	58	5.299	< **.001**	1.285
	Contempt	Symbolic entropy	34	3.402	.469	4.217	.456	66	-7.273	< **.001**	-1.764
		Coherence	34	.036	.006	.033	.002	37	3.273	**.002**	.794
		MDRQA (%REC)	34	17.62	10.31	1.19	1.19	34	9.229	< **.001**	2.238

Table 11

Overview results motor synchrony compared to surrogate dataset 2

Level	Emotion	Measure	n	M	SD	M (sur)	SD (sur)	df	t	p	Cohen's d
L2	Happiness	Symbolic entropy	34	2.506	.596	2.549	.590	66	-.296	.768	-.072
		Coherence	34	.045	.011	.034	.006	51	5.138	< **.001**	1.246
		MDRQA (%REC)	34	24.21	12.68	18.61	10.87	65	1.956	.055	.474
	Sadness	Symbolic entropy	34	3.752	.330	3.767	.253	62	-.217	.829	-.053
		Coherence	34	.038	.007	.033	.002	39	3.210	**.003**	.779
		MDRQA (%REC)	34	5.91	4.26	4.90	4.14	66	.988	.327	.240
	Surprise	Symbolic entropy	34	3.762	.236	3.779	.231	66	-.291	.772	-.070
		Coherence	34	.038	.008	.034	.003	34	3.120	**.003**	.757
		MDRQA (%REC)	34	8.39	4.92	6.82	3.51	60	1.510	.136	.366
	Fear	Symbolic entropy	34	4.166	.066	4.165	.060	65	.03	.976	.007
		Coherence	34	.037	.006	.033	.003	45	3.429	**.001**	.832
		MDRQA (%REC)	34	3.60	3.23	2.88	1.73	51	1.161	.251	.282
	Anger	Symbolic entropy	34	3.972	.248	3.984	.257	66	-.201	.841	-.049
		Coherence	34	.036	.004	.034	.002	48	2.461	.018	.597
		MDRQA (%REC)	34	3.11	2.66	2.78	1.78	58	.600	.551	.146
	Contempt	Symbolic entropy	34	3.412	.491	3.461	.431	65	-.434	.665	-.105
		Coherence	34	.038	.005	.034	.003	54	3.641	**.001**	.883
		MDRQA (%REC)	34	12.63	7.68	9.83	6.17	63	1.657	.103	.402
L3	Happiness	Symbolic entropy	34	2.218	.584	2.233	.491	64	-.112	.991	-.027
		Coherence	34	.044	.014	.034	.006	44	3.762	< **.001**	.912
		MDRQA (%REC)	34	26.52	13.06	21.84	10.87	64	1.607	.113	.390
	Sadness	Symbolic entropy	34	3.714	.362	3.722	.285	63	-.111	.912	-.027
		Coherence	34	.036	.007	.033	.003	39	1.929	.061	.533
		MDRQA (%REC)	34	6.59	6.27	5.17	2.83	46	1.204	.235	.292
	Surprise	Symbolic entropy	34	3.825	.227	3.839	.179	63	-.290	.773	-.070
		Coherence	34	.036	.006	.033	.003	44	2.564	**.014**	.622
		MDRQA (%REC)	34	9.56	5.26	8.28	3.53	58	1.173	.245	.285
	Fear	Symbolic entropy	34	4.164	.073	4.173	.050	58	-.569	.571	-.138
		Coherence	34	.036	.005	.033	.002	45	2.606	**.012**	.632
		MDRQA (%REC)	34	4.14	3.59	3.49	2.31	56	.883	.381	.214
	Anger	Symbolic entropy	34	3.854	.266	3.865	.307	65	-.168	.867	-.041
		Coherence	34	.036	.006	.033	.003	54	2.741	**.008**	.665
		MDRQA (%REC)	34	5.18	4.49	4.75	3.67	63	.431	.668	.104
	Contempt	Symbolic entropy	34	3.402	.469	3.424	.476	66	-.199	.843	-.048
		Coherence	34	.036	.006	.033	.003	51	2.537	**.014**	.615
		MDRQA (%REC)	34	12.22	8.88	9.50	5.66	56	1.509	.137	.366

6.2 Relationship Physiological Synchrony and Team Adaptation

The second research question centers around the relationship between physiological synchrony and team adaptation. To that end, correlation matrices were obtained by calculating Pearson correlation coefficients. The matrices allow for investigating the direct relationship between physiological synchrony in both levels and team adaptation, as well as for providing insights in relationships among measures. In the matrices, a distinction is made between the control condition and the experimental condition. The results are organized into three subsections: one for cardiovascular synchrony, one for electrodermal synchrony, and one for motor synchrony.

6.2.1 Relationship Cardiovascular Synchrony and Team Adaptation ***[Research Question 2.1]***

Table 12 reports correlation matrices for cardiovascular synchrony measures and team adaptation for the whole sample, the control condition and the experimental condition. It was hypothesized that cardiovascular synchrony would positively relate to team adaptation. When looking at the whole sample, only the relationship between cardiovascular synchrony in the MdRQA measure in the third level and team adaptation was found significant ($r = -.41, p < .05$). The Pearson correlation coefficient indicates that higher synchrony in the MdRQA measure in the third level was associated with lower values of perceived team adaptation. This relationship is even stronger in the control condition ($r = -.65, p < .05$). Other relationships between cardiovascular synchrony and team adaptation were found non-significant. These results do not support the hypothesis that cardiovascular synchrony is positively related to team adaptation during the experiment.

6.2.2 Relationship Electrodermal Synchrony and Team Adaptation ***[Research Question 2.2]***

Table 13 reports correlation matrices for electrodermal synchrony measures and team adaptation for the whole sample, the control condition and the experimental condition. It was hypothesized that electrodermal synchrony would positively relate to team adaptation. When looking at the whole sample and the control condition, no significant relationships were found between electrodermal synchrony and team adaptation. In the experimental condition only the relationship between electrodermal synchrony in the MdRQA measure in the third level and team adaptation was found significant ($r = -.50, p < .05$). The Pearson correlation coefficient indicates that higher synchrony in the MdRQA measure in the third level was associated with lower values of perceived team adaptation. Other relationships between electrodermal synchrony and team adaptation were found non-significant. These results do not support the hypothesis that electrodermal synchrony is positively related to team adaptation during the experiment.

6.2.3 Relationship Motor Synchrony and Team Adaptation **[Research Question 2.3]**

This section report correlation matrices for motor synchrony measures and team adaptation for the whole sample, the control condition and the experimental condition. There are six tables, one for each facial expression (i.e., *happiness, sadness, surprise*, *fear*, *anger* and *contempt*). It was hypothesized that motor synchrony would occur during the experiment.

Happiness. Table 14 reports correlation matrices for motor synchrony measures in the happiness facial expression and team adaptation for the whole sample, the control condition and the experimental condition. No significant relationships were found between synchrony measures and team adaptation.

Sadness. Table 15 reports correlation matrices for motor synchrony measures in the sadness facial expression and team adaptation for the whole sample, the control condition and the experimental condition. No significant relationships were found between synchrony measures and team adaptation.

Surprise. Table 16 reports correlation matrices for motor synchrony measures in the surprise facial expression and team adaptation for the whole sample, the control condition and the experimental condition. When looking at the whole sample, only the relationship between motor synchrony in the surprise facial expression in the symbolic entropy measure in the second level and team adaptation was found significant ($r = .45, p < .01$). The Pearson correlation coefficient indicates that higher synchrony in the symbolic entropy measure in the second level (i.e., lower symbolic entropy values) was associated with lower values of perceived team adaptation. This relationship is even stronger in the control condition ($r = .66, p < .01$). Other relationships between motor synchrony in the surprise facial expression and team adaptation were found non-significant.

Fear. Table 17 reports correlation matrices for motor synchrony measures in the fear facial expression and team adaptation for the whole sample, the control condition and the experimental condition. When looking at the whole sample, only the relationship between motor synchrony in the surprise facial expressions in the MdRQA measure in the second level and team adaptation was found significant ($r = -.42, p < .05$). The Pearson correlation coefficient indicates that higher synchrony in the MdRQA measure in the second level was associated with lower values of perceived team adaptation. This relationship is even stronger in the control condition ($r = -.59$, $p < .05$). Moreover, also the relationship between motor synchrony in the fear facial expressions in the MdRQA measure in the third level and team adaptation was found significant in the control condition ($r = -.52$, $p < .05$). Other relationships between motor synchrony in the fear facial expression and team adaptation were found non-significant.

Anger. Table 18 reports correlation matrices for motor synchrony measures in the anger facial expression and team adaptation for the whole sample, the control condition and the experimental condition. When looking at the whole sample, only the relationship between motor synchrony in the anger facial expressions in the MdRQA measure in the second level and team adaptation was found significant ($r = -.36$, $p < .05$). The Pearson correlation coefficient indicates that higher synchrony in the MdRQA measure in the second level was associated with lower values of perceived team adaptation. Other relationships between motor synchrony in the anger facial expression and team adaptation were found non-significant.

Contempt Table 19 reports correlation matrices for motor synchrony measures in the contempt facial expression and team adaptation for the whole sample, the control condition and the experimental condition. No significant relationships were found between synchrony measures and team adaptation.

Combining the results. In all, although results differ somewhat among facial expressions, they are generally similar. That is, most of the investigated relationships were found non-significant. The relationships that were found significant indicate a negative relationship between motor synchrony and team adaptation. As such, these results do not support the hypothesis that motor synchrony is positively related to team adaptation during the experiment.

Table 12

Correlation coefficients for cardiovascular synchrony and team adaptation

	1	**2**	**3**	**4**	**5**	**6**	**7**
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.52****	1					
3. L2 Coherence	-.27	-.18	1				
4. L3 Coherence	-.05	-.03	0	1			
5. L2 MdRQA	**-.72****	**-.46***	.32	.02	1		
6. L3 MdRQA	-.21	-.34	.04	.36	.23	1	
7. Team adaptation	-.12	.01	-.03	-.31	-.03	**-.41***	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.54	1					
3. L2 Coherence	-.34	.05	1				
4. L3 Coherence	.16	.30	.14	1			
5. L2 MdRQA	**-.78****	**-.56***	.50	-.03	1		
6. L3 MdRQA	-.29	-.14	0	.21	.20	1	
7. Team adaptation	.07	.13	-.31	-.49	-.19	**-.65***	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.49	1					
3. L2 Coherence	-.18	-.46	1				
4. L3 Coherence	-.25	-.39	-.17	1			
5. L2 MdRQA	**-.66****	-.34	.05	.07	1		
6. L3 MdRQA	-.14	**-.55***	.08	**.52***	.25	1	
7. Team adaptation	-.21	-.05	.14	-.25	.06	-.33	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 13

Correlation coefficients for electrodermal synchrony and team adaptation

	1	**2**	**3**	**4**	**5**	**6**	**7**
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.43****	1					
3. L2 Coherence	.29	.05	1				
4. L3 Coherence	-.09	-.11	.15	1			
5. L2 MdRQA	-.28	-.25	.21	.09	1		
6. L3 MdRQA	.04	**-.37***	.09	.28	.15	1	
7. Team adaptation	.01	.17	-.07	-.19	.12	-.31	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.53***	1					
3. L2 Coherence	.41	.06	1				
4. L3 Coherence	-.24	-.07	.11	1			
5. L2 MdRQA	-.31	-.33	.31	.29	1		
6. L3 MdRQA	-.02	-.42	.01	.18	.35	1	
7. Team adaptation	.05	.15	-.01	-.30	.18	-.05	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.35	1					
3. L2 Coherence	.22	.02	1				
4. L3 Coherence	.16	-.16	.18	1			
5. L2 MdRQA	-.27	-.16	.09	-.09	1		
6. L3 MdRQA	.07	-.32	.25	.40	-.05	1	
7. Team adaptation	-.01	.20	-.13	-.13	.09	**-.50***	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 14

Correlation coefficients for motor synchrony and team adaptation – Happiness

	1	**2**	**3**	**4**	**5**	**6**	**7**
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.51****	1					
3. L2 Coherence	-.11	.16	1				
4. L3 Coherence	-.18	-.18	-.07	1			
5. L2 MdRQA	-.09	-.03	**.54****	-.09	1		
6. L3 MdRQA	-.32	-.33	.13	**.52****	.24	1	
7. Team adaptation	-.04	-.18	-.03	.12	-.01	-.10	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.37	1					
3. L2 Coherence	-.39	.08	1				
4. L3 Coherence	-.03	-.16	-.28	1			
5. L2 MdRQA	-.18	.07	**.60****	-.06	1		
6. L3 MdRQA	**-.59****	**-.57***	.29	.20	.30	1	
7. Team adaptation	.14	-.21	.06	-.08	.28	.26	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.59***	1					
3. L2 Coherence	-.05	.16	1				
4. L3 Coherence	-.24	-.17	.16	1			
5. L2 MdRQA	-.13	-.20	.40	-.09	1		
6. L3 MdRQA	-.28	-.26	-.01	**.64****	.22	1	
7. Team adaptation	-.13	-.15	-.10	.20	-.27	-.25	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 15

Correlation coefficients for motor synchrony and team adaptation – Sadness

	1	**2**	**3**	**4**	**5**	**6**	**7**
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.66****	1					
3. L2 Coherence	**-.37***	-.15	1				
4. L3 Coherence	-.12	-.27	.32	1			
5. L2 MdRQA	**-.59****	**-.36***	**.52****	-.20	1		
6. L3 MdRQA	**-.66****	**-.56****	**.39***	.29	**.65****	1	
7. Team adaptation	.24	.03	-.15	.16	-.27	-.15	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.66****	1					
3. L2 Coherence	-.21	-.33	1				
4. L3 Coherence	-.17	-.01	.34	1			
5. L2 MdRQA	-.37	**-.49***	.37	-.26	1		
6. L3 MdRQA	-.47*	-.35	.17	.11	**.52***	1	
7. Team adaptation	-.01	.08	.01	-.17	-.16	-.37	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.66****	1					
3. L2 Coherence	-.44	.01	1				
4. L3 Coherence	-.06	-.36	.31	1			
5. L2 MdRQA	**-.72****	-.29	**.60***	-.20	1		
6. L3 MdRQA	**-.73****	**-.70****	.44	.26	**.74****	1	
7. Team adaptation	-.43	.06	-.28	.25	-.33	-.16	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 16

Correlation coefficients for motor synchrony and team adaptation – Surprise

	1	**2**	**3**	**4**	**5**	**6**	**7**
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.28	1					
3. L2 Coherence	-.15	.08	1				
4. L3 Coherence	-.22	**-.53****	.18	1			
5. L2 MdRQA	**-.37***	.05	**.35***	-.14	1		
6. L3 MdRQA	-.31	-.33	.16	.23	**.55****	1	
7. Team adaptation	**.45****	.14	-.12	.02	-.31	-.08	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.51***	1					
3. L2 Coherence	.25	.36	1				
4. L3 Coherence	-.22	.16	.34	1			
5. L2 MdRQA	-.22	-.17	-.07	.22	1		
6. L3 MdRQA	-.27	-.15	-.09	.22	**.30***	1	
7. Team adaptation	**.66****	.43	.01	-.43	-.40	-.16	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.20	1					
3. L2 Coherence	**-.50***	-.09	1				
4. L3 Coherence	-.24	**-.79****	.11	1			
5. L2 MdRQA	**-.50***	.13	**.58***	-.27	1		
6. L3 MdRQA	-.28	-.43	.24	.24	**.63****	1	
7. Team adaptation	.35	0	-.23	.22	-.27	-.08	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 17

Correlation coefficients for motor synchrony and team adaptation – Fear

	1	2	3	4	5	6	7
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.17	1					
3. L2 Coherence	-.27	.21	1				
4. L3 Coherence	-.17	**-.40***	-.09	1			
5. L2 MdRQA	**-.42***	-.09	**.56****	-.19	1		
6. L3 MdRQA	-.24	-.25	**.39***	**.36***	**.55****	1	
7. Team adaptation	.23	.17	-.18	.08	**-.42***	-.16	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.45	1					
3. L2 Coherence	-.23	.17	1				
4. L3 Coherence	.05	.03	.23	1			
5. L2 MdRQA	**-.62****	**-.51***	.01	-.03	1		
6. L3 MdRQA	**-.48***	-.36	.12	.37	.47	1	
7. Team adaptation	.27	.13	.08	-.43	**-.59***	**-.52***	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	-.07	1					
3. L2 Coherence	-.33	.22	1				
4. L3 Coherence	.26	**-.66****	-.28	1			
5. L2 MdRQA	-.28	.14	**.87****	-.29	1		
6. L3 MdRQA	-.18	-.26	.48	.31	**.60***	1	
7. Team adaptation	.19	.19	-.34	.30	-.33	-.06	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 18

Correlation coefficients for motor synchrony and team adaptation – Anger

	1	2	3	4	5	6	7
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.68****	1					
3. L2 Coherence	-.26	-.24	1				
4. L3 Coherence	-.15	-.32	.12	1			
5. L2 MdRQA	**-.69****	**-.47****	**.60****	.03	1		
6. L3 MdRQA	**-.55***	**-.68****	.26	**.60****	**.54****	1	
7. Team adaptation	.27	.07	-.31	.15	**-.36***	-.02	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.46	1					
3. L2 Coherence	.25	.05	1				
4. L3 Coherence	.06	-.04	.34	1			
5. L2 MdRQA	**-.67****	-.38	-.05	.11	1		
6. L3 MdRQA	**-.60****	**-.77****	-.10	.22	**.74****	1	
7. Team adaptation	.09	.08	-.14	-.19	-.26	-.21	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	**.74****	1					
3. L2 Coherence	**-.62***	-.39	1				
4. L3 Coherence	-.06	-.29	-.10	1			
5. L2 MdRQA	**-.72****	-.47	**.90****	-.10	1		
6. L3 MdRQA	-.47	**-.62***	.40	**.67****	.46	1	
7. Team adaptation	.48	.12	-.46	.31	-.44	.07	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

Table 19

Correlation coefficients for motor synchrony and team adaptation – Contempt

	1	**2**	**3**	**4**	**5**	**6**	**7**
Whole sample							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.32	1					
3. L2 Coherence	-.37	-.11	1				
4. L3 Coherence	**-.35***	-.16	-.25	1			
5. L2 MdRQA	**-.44****	-.24	**.63****	-.09	1		
6. L3 MdRQA	**-.53***	**-.56****	.37	**.48****	**.37***	1	
7. Team adaptation	.09	.01	-.09	.20	-.12	0	1
Control							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.34	1					
3. L2 Coherence	-.25	-.02	1				
4. L3 Coherence	-.12	-.08	-.28	1			
5. L2 MdRQA	.13	-.18	.52	.05	1		
6. L3 MdRQA	-.17	**-.59***	.44	.21	.28	1	
7. Team adaptation	.22	-.22	-.02	-.02	.16	.28	1
Experimental							
1. L2 Symbolic entropy	1						
2. L3 Symbolic entropy	.36	1					
3. L2 Coherence	**-.64****	-.21	1				
4. L3 Coherence	-.44	-.24	-.22	1			
5. L2 MdRQA	**-.72****	-.29	**.84****	-.17	1		
6. L3 MdRQA	**-.74****	**-.55***	.24	**.70****	.42	1	
7. Team adaptation	.05	.19	-.14	.30	-.30	-.15	1

Notes: * significant at the .05 level (two-tailed); ** significant at the .01 level (two-tailed)

6.3 Effect of an Unexpected Event

The third research question focuses on the effect of the intervention during the experiment on team adaptation and physiological synchrony. To that end, a Welch's independent samples t-test was performed on team adaptation scores to provide insight in differences in team adaptation scores between the control condition and the experimental condition. Moreover, two-way ANOVA analyses were conducted on physiological synchrony scores with one factor being condition (2 levels: control condition and experimental condition) and one factor being level (2 levels: before and after the unexpected event). The results are organized into four subsections: one for team adaptation, one for cardiovascular synchrony, one for electrodermal synchrony, and one for motor synchrony.

6.3.1 Effect of an Unexpected Event on Team Adaptation ***[Research Question 3.1]***

Table 20 reports the results of the Welch's t-test on the difference in team adaptation scores between the control condition and the experimental condition. It was hypothesized that the unexpected event would have a negative influence on team adaptation scores. The results reveal that there is no statistically significant difference in mean team adaptation scores between the control condition and the experimental condition ($t = 2.026$, $p = 0.969$), indicating that the unexpected event did not affect team adaptation scores. As such, these results do not support the hypothesis that an unexpected event negatively influences team adaptation.

Table 20

Team adaptation questionnaire statistics

n experimental	*M* experimental	*SD* experimental	n control	*M* control	*SD* control	t	p
21	40.55	4.64	23	40.60	3.49	2.026	.969

6.3.2 Effect of an Unexpected Event on Cardiovascular Synchrony ***[Research Question 3.2]***

Table 21 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on cardiovascular synchrony. It was hypothesized that the unexpected event would negatively influence cardiovascular synchrony. The results reveal that, in all measures, there were no statistically significant results found for the main effects of condition and level, and the interaction effect of condition and level. As such, the results do not support the hypothesis that an unexpected event negatively influences cardiovascular synchrony.

6.3.3 *Effect of an Unexpected Event on Electrodermal Synchrony* **[Research Question 3.3]**

Table 22 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on electrodermal synchrony. It was hypothesized that the unexpected event would negatively influence electrodermal synchrony. The results reveal that, in both the symbolic entropy measure and the MdRQA measure, there were no statistically significant results found for the main effects of condition and level, and the interaction effect of condition and level. In the coherence measure, the main effect of level was found statistically significant (*F(1) = 7.210, p = .009*), indicating that coherence scores significantly changed from the second level to the third level (*Level 2: M = .104, SD = .007; Level 3: M = .108, SD = .008)*. Other effects in the coherence measure were found non-significant. In all, the results reveal that the unexpected event did not have a statistically significant effect on electrodermal synchrony. As such, the results do not support the hypothesis that an unexpected event negatively influences electrodermal synchrony.

6.3.4 *Effect of an Unexpected Event on Motor Synchrony* **[Research Question 3.4]**

This section reports two-way ANOVA analyses on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on motor synchrony. There are six tables, one for each facial expression (i.e., *happiness, sadness, surprise, fear, anger* and *contempt*). It was hypothesized that the unexpected event would have a negative influence on motor synchrony.

Happiness. Table 23 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on motor synchrony in the happiness facial expression. The results reveal that, in both the MdRQA measure and coherence measure, there were no statistically significant results found for the main effects of condition and level, and the interaction effect of condition and level. In the symbolic entropy measure, the main effect of the condition (*F(1) = 4.189, p = .045*) as well as the main effect of level (*F(1) = 4.027, p = .049*) were found statistically significant. This indicates that both condition (*Experimental: M = 2.210, SD = .608; Control: M = 2.497, SD = .557*) and going from the second to the third level (*Level 2: M = 2.506, SD = .596; Level 3: M = 2.218, SD = .584*) had a statistically significant effect on motor synchrony in the happiness facial expression in the symbolic entropy measure. The interaction effect of condition and level in the symbolic entropy measure, however, was found non-significant (*F(1)*

= .516, p = .475), indicating that the effect of the unexpected event was non-significant. In all, the results reveal that the unexpected event did not have a statistically significant effect on motor synchrony in the happiness facial expression.

Sadness. Table 24 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on motor synchrony in the sadness facial expression. The results reveal that, in all measures, there were no statistically significant results found for the main effects of condition and level, nor for the interaction effect of condition and level. As such, this indicates that the unexpected event did not have a statistically significant effect on motor synchrony in the sadness facial expression.

Surprise. Table 25 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on motor synchrony in the sadness surprise expression. The results reveal that, in all measures, there were no statistically significant results found for the main effects of condition and level, nor for the interaction effect of condition and level. As such, this indicates that the unexpected event did not have a statistically significant effect on motor synchrony in the surprise facial expression.

Fear. Table 26 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on motor synchrony in the fear facial expression. The results reveal that, in all measures, there were no statistically significant results found for the main effects of condition and level, nor for the interaction effect of condition and level. As such, this indicates that the unexpected event did not have a statistically significant effect on motor synchrony in the fear facial expression.

Anger. Table 27 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on motor synchrony in the anger facial expression. The results reveal that, in all measures, statistically significant results were found for the main effect of condition on motor synchrony in the anger facial expression (*Symbolic entropy: F(1) = 11.658, p = .001; Coherence: F(1) = 4.838, p = .031; MdRQA: F(1) = 4.835, p = .032*), indicating a significant difference between the experimental condition and the control condition (*Symbolic entropy – Experimental: M = 3.807, SD = .272; Control: M = 4.007, SD = .217 | MdRQA –*

Experimental: M = 5.16, SD = 4.90; Control: M = 3.24, SD = 2.17 | Coherence – Experimental: M = .037, SD = .006; Control: M = .034, SD = .004). Furthermore, the main effects of level in the symbolic entropy measure and the MdRQA measure were found statistically significant as well (*Symbolic entropy: F(1) = 4.164, p = .045; MdRQA: F(1) = 5.860, p = .018*), indicating that motor synchrony in the anger facial expression was affected by going from the second level to the third level for the symbolic entropy and MdRQA measure (*Symbolic entropy – Level 2: M = 3.972, SD = .248; Level 3: M = 3.854, SD = .266 | MdRQA – Level 2: M = 3.11, SD = 2.66; Level 3: M = 5.18, SD = 4.49*). However, in all measures, the interaction effects of the unexpected event and time were found non-significant. As such, this indicates that the unexpected event did not have a statistically significant effect on motor synchrony in the anger facial expression.

Contempt. Table 28 reports the results of a two-way ANOVA analysis on the main effects of condition and level, and the interaction effect of condition and level (i.e., the unexpected event) on motor synchrony in the contempt facial expression. The results reveal that, in all measures, there were no statistically significant results found for the main effects of condition and level, and the interaction effect of condition and level. As such, this indicates that the unexpected event did not have a statistically significant effect on motor synchrony in the contempt facial expression.

Combining the results. In all, although some significant results were found with regards to the main effects of condition and level differ among facial expressions, results on the effect of the unexpected event are similar: that is, in none of the facial expressions, significant results were found for the interaction effect of condition and level. This reveals that the unexpected event did not have a statistically significant effect on motor synchrony. As such, these results do not support the hypothesis that an unexpected event negatively influences motor.

Table 21

Two-way ANOVA results for cardiovascular synchrony

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	.017	1	.017	.513	.477
	Level	.028	1	.028	.811	.372
	Interaction	.004	1	.004	.104	.748
	Error	1.767	52	.034		
Coherence	Condition	.000	1	.000	.057	.813
	Level	.002	1	.002	2.526	.118
	Interaction	.000	1	.000	.208	.650
	Error	.035	52	.001		
MDRQA	Condition	.000	1	.000	.485	.489
	Level	.000	1	.000	.769	.385
	Interaction	.000	1	.000	.097	.756
	Error	.030	52	.001		

Table 22

Two-way ANOVA results for electrodermal synchrony

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	.000	1	.000	.434	.512
	Level	.003	1	.003	3.193	.078
	Interaction	.001	1	.001	1.072	.304
	Error	.055	70	.001		
Coherence	Condition	.000	1	.000	1.552	.217
	Level	.000	1	.000	7.210	**.009**
	Interaction	.000	1	.000	.269	.605
	Error	.004	70	.000		
MDRQA	Condition	.000	1	.000	.163	.687
	Level	.006	1	.006	2.024	.159
	Interaction	.001	1	.001	.197	.659
	Error	.201	70	.003		

Table 23

Two-way ANOVA results for motor synchrony – Happiness

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	1.402	1	1.402	4.189	.045
	Level	1.384	1	1.384	4.027	.049
	Interaction	.173	1	.173	.516	.475
	Error	21.421	64	.335		
Coherence	Condition	.000	1	.000	.104	.748
	Level	.000	1	.000	.091	.764
	Interaction	.001	1	.001	3.102	.083
	Error	.010	64	.000		
MDRQA	Condition	.018	1	.018	1.084	.302
	Level	.009	1	.009	.564	.455
	Interaction	.001	1	.001	.079	.780
	Error	1.073	64	.017		

Table 24

Two-way ANOVA results for motor synchrony – Sadness

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	.216	1	.216	1.807	.184
	Level	.022	1	.022	.182	.671
	Interaction	.031	1	.031	.258	.613
	Error	7.667	64	.120		
Coherence	Condition	.000	1	.000	2.146	.148
	Level	.000	1	.000	1.225	.273
	Interaction	.000	1	.000	.001	.970
	Error	.003	64	.000		
MDRQA	Condition	.009	1	.009	3.438	.068
	Level	.001	1	.001	.407	.526
	Interaction	.008	1	.008	2.792	.100
	Error	.173	64	.003		

Table 25

Two-way ANOVA results for motor synchrony – Surprise

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	.035	1	.035	.655	.421
	Level	.078	1	.078	1.468	.230
	Interaction	.117	1	.117	2.205	.142
	Error	3.399	64	.053		
Coherence	Condition	.000	1	.000	.498	.483
	Level	.000	1	.000	1.970	.165
	Interaction	.000	1	.000	.250	.619
	Error	.004	64	.000		
MDRQA	Condition	.004	1	.004	1.734	.193
	Level	.003	1	.003	.992	.323
	Interaction	.002	1	.002	.635	.429
	Error	.120	64	.002		

Table 26

Two-way ANOVA results for motor synchrony – Fear

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	.002	1	.002	.349	.557
	Level	.000	1	.000	.004	.952
	Interaction	.000	1	.000	.058	.811
	Error	.317	64	.005		
Coherence	Condition	.000	1	.000	1.740	.192
	Level	.000	1	.000	1.060	.307
	Interaction	.000	1	.000	.171	.680
	Error	.002	64	.000		
MDRQA	Condition	.002	1	.002	1.581	.213
	Level	.001	1	.001	.482	.490
	Interaction	.001	1	.001	.749	.390
	Error	.074	64	.001		

Table 27

Two-way ANOVA results for motor synchrony – Anger

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	.672	1	.672	11.658	.001
	Level	.240	1	.240	4.164	.045
	Interaction	.002	1	.002	.027	.871
	Error	3.691	64	.058		
Coherence	Condition	.000	1	.000	4.838	.031
	Level	.000	1	.000	.001	.975
	Interaction	.000	1	.000	1.439	.235
	Error	.002	64	.000		
MDRQA	Condition	.006	1	.006	4.835	.032
	Level	.008	1	.008	5.860	.018
	Interaction	.001	1	.001	.911	.343
	Error	.082	64	.001		

Table 28

Two-way ANOVA results for motor synchrony – Contempt

Measure	Predictor	Sum of squares	df	Mean square	F	p
Symbolic entropy	Condition	.001	1	.001	.004	.950
	Level	.001	1	.001	.003	.959
	Interaction	.078	1	.078	.331	.567
	Error	15.122	64	.236		
Coherence	Condition	.000	1	.000	.250	.619
	Level	.000	1	.000	.448	.506
	Interaction	.000	1	.000	2.075	.155
	Error	.002	64	.000		
MDRQA	Condition	.011	1	.011	1.599	.211
	Level	.000	1	.000	.052	.820
	Interaction	.002	1	.002	.224	.637
	Error	.442	64	.007		

7 DISCUSSION

The current study was concerned with the relationship between physiological synchrony – in heart rate, skin conductance and facial expressions – on perceived levels of team adaptation. Specifically, three research questions were investigated: (1) Does physiological synchrony occur during collaborative online game play in four-person teams? (2) How does physiological synchrony relate to team adaptation during collaborative online game play in four-person teams? (3) How does an unexpected event influence physiological synchrony and team adaptation during collaborative game play in a four-person team? In this section, these research questions will be addressed and results will be discussed and interpretated in more detail.

Presence of Physiological Synchrony

Results reveal that physiological synchrony occurred during the experiment in the current study. That is, in nearly all synchrony measures, in both the second and the third level in the game, physiological synchrony was found significantly higher in the original dataset compared to the first surrogate dataset. This indicates that cardiovascular synchrony, electrodermal synchrony and motor synchrony occurred above levels expected by chance. In essence, these results reveal that physiological synchrony did, indeed, occur during the experiment, as is in line with hypotheses 1.1, 1.2 and 1.3. When comparing with the second surrogate dataset, however, most of the differences were found non-significant, indicating that cardiovascular synchrony, electrodermal synchrony and motor synchrony did not occur above levels expected for teams composed of non-cooperating persons performing the same task. These results leave room for interpretation as the results indicate that physiological synchrony did not necessarily emerge from cooperative (gaming) contacts, with feelings and behaviors between team members, as was the main rationale behind hypotheses 1.1, 1.2 and 1.3. After all, teams in the second surrogate dataset consisted of team members that did not actually work together and still showed levels of synchrony that were not significantly different from teams composed of team members that did work together.

The findings imply that teams were very similar in the way they behaved and worked together, resulting in similar heart rate patterns, skin conductance levels and facial expressions among teams during the experiment. As a result, individuals did not only synchronize with fellow team members, but also, indirectly, with any other individual from a random team. A possible explanation for this finding could be that physiological synchrony did not necessarily emerge from cooperative contacts, but could have been the result of the game itself. That is, actions in the game might have triggered certain behaviors that were similar among all individuals and, as such, individuals were not synchronized as a result from cooperative contacts, but rather from the way they experienced the game. In essence, this boils down to the following: physiological synchrony in the current study could have been the result of conditional similarities, rather than interpersonal dynamics. Such explanation follows a theory about physiological synchrony introduced by Palumbo and colleagues (2017), who argued that physiological synchrony cannot only result from causal interdependence (i.e., cooperative contacts; reactivity in one person causes reactivity in another), but also from matched dependence on an external variable (e.g., actions in the game, similar conditions). Given the results, it is likely that the latter one was the main driver for physiological synchrony in the current study. Such finding is also in line with a study by Strang and colleagues (2014), where the researchers found that, similar to the current study, physiological synchrony within teams playing video games was not significantly greater than data randomly paired from other teams, thereby suggesting that physiological synchrony was due to conditional similarities, rather than interpersonal dynamics.

It should, however, be noted that not all differences between the original data and surrogate dataset 2 were found non-significant. In fact, in the coherence measure, statistically significant differences were found between the two datasets in all facial expressions, indicating that the coherence measure reflected levels of motor synchrony above those expected for teams composed of non-cooperating persons performing the same task. It is intriguing that the symbolic entropy measure and the MdRQA measure did not capture this effect, and, therefore, a possible explanation may lie in the differences between the measures and the aspects of synchrony they capture.

As described in the *method* section, symbolic entropy captures behavior synchronized around some shared pattern, based on the states of a team. In order to obtain low values of entropy, which are associated with higher levels of synchrony, it is not necessarily needed that team members are actually synchronized. This can best be illustrated with the following example: assume a dyad performing a collaborative task. Throughout the first minute of the task, the state (see *method*) of the dyad is either ‘low-high’, ‘medium-medium’ or ‘high-low’. As such, the entropy for this time window would be very low as there are only three states, whereas the dyad itself was not synchronized at all (in fact, physiological signals moved in antiphase). Similar effects can occur in the MdRQA measure, which, as described in the *method* section, captures repetition of the same or similar values between time series. By doing so, it reflects recurring patterns within a team, but it does not say anything about how the physiological signals of team members go up and down simultaneously over time. Both symbolic entropy and MdRQA could, therefore, potentially be interpreted as measures of regularity rather than synchrony in the strict sense.

Coherence, on the other hand, reflects to what extent the signals of the team members fluctuate with similar frequencies (see *method*). As such, it captures more directly how signals of team members fluctuate simultaneously over time than the symbolic entropy measure and the MdRQA measure do. This might also explain why the coherence measure captured differences with surrogate dataset 2, and symbolic entropy and MdRQA did not: as facial expressions are strongly associated with communication (Frith, 2009), it is very well possible that when one team member displays a certain facial expression, other team members will react with the same facial expression. As such, the presence of facial expressions and the frequency at which they occur would be roughly the same among team members, resulting in high levels of synchrony (or at least levels higher than expected for teams in which team members could not see each other). With the coherence measure being able to capture such 'direct' forms of synchrony, and the symbolic entropy measure and MdRQA measure not, this possibly explains why the coherence measure captured higher synchrony in the original dataset compared the surrogate dataset 2, and why this effect was not found in the symbolic entropy measure and the MdRQA measure.

Relationship between Physiological Synchrony and Team Adaptation

Most of the relationships between physiological synchrony measures in the cardiovascular, electrodermal and motor modalities, and team adaptation were found non-significant. Results that were significant, although not always consistent throughout modalities and conditions, were indicative of a negative relationship between physiological synchrony and team adaptation. That is, higher levels of synchrony being associated with lower levels of perceived team adaptation. This is interesting as it was hypothesized that physiological synchrony would positively, instead of negatively, relate to team adaptation. There are several possible explanations for this finding.

A first explanation may lie in the computation of physiological synchrony and the synchrony measures that were used in this study to do so. In the current study, physiological synchrony was computed in the synchrony measures over a specified period of time (being 2 minutes and 22 seconds). As such, the synchrony measures reflect how well synchronized teams were over that whole period of time, without taking into account how synchrony levels fluctuated throughout the time. In order to capture forms of synchrony crucial for team adaptation and its underlying constructs, it might have been more suitable to analyze synchrony scores over smaller segments, which is supported by the notion that synchrony may not occur consistently across a group task and instead has time-varying properties (Likens & Wiltshire, 2021; Mayo & Gordon, 2020; Wiltshire et al., 2019).

It should also be stressed that the synchrony measures in the current study in themselves might not have been suitable to capture the comprehensive concept of physiological synchrony. As described in the *method* section, each of the three synchrony measures captures different aspects of synchrony and, as such, their relationships with team adaptation might not have captured a relationship between the physiological synchrony and team adaptation, but rather a relationship between aspects of synchrony and team adaptation. In fact, it is even questionable if all the measures did actually capture synchrony, and not levels of regularity as discussed earlier in this section. Although the concepts of regularity and synchrony show some overlap, forms of regularity do not necessarily reflect synchrony. In the current study, this distinction was not made and all the measures were considered to represent the comprehensive concept of physiological synchrony.

In the light of the above, the found negative relationships might not even be surprising. As symbolic entropy and MdRQA can be considered as measures of regularity rather than synchrony, and as the negative relationships were only found statistically significant in these measures, one can argue that the found relationships were relationships between regularity and team adaptation, rather than between synchrony and team adaptation. In other words, the found relationships implicate the following: the more 'fixed' patterns within a team, the lower the levels of team adaptation. Intuitively, this makes sense as teams that are stuck within a certain rhythm/routine do not seek out for innovative ways or alternative plans when faced with changing demands and, as such, they would have lower levels of team adaptation.

A second explanation may involve the conditions in the current study. During the experiment, participants were allowed to interact freely with each other within the constraints placed upon them for completing the given gaming task. However, as the gaming task was played on computers, interaction between participants was remote rather than interpersonal. As such, interactions patterns that are usual during face-to-face collaboration, such as eye contacts between participants or gestures while explaining something to another participant, would possibly have been harder to establish in the current study than it would have been in face-to-face settings. When constructing the hypotheses in the current study, this was not taken into account, and results from studies using remote settings and results from studies using face-to-face settings were used interchangeably. Research has already shown that the lack of face-to-face contacts influences levels physiological synchrony (e.g., Behrens et al., 2020), and it is possible that this subsequently impacts relationships between physiological synchrony and team adaptation constructs. As such, results from studies on relationships between physiological synchrony in face-to-face settings and team adaptation constructs may not have been suitable for the current study and inappropriate hypotheses might have been constructed.

Finally, it is possible that the relationship between physiological synchrony and team adaptation is, indeed, negative in nature. If so, this indicates that team adaptation is more complex than was assumed when building hypotheses. As there had been no research on the direct relationship between physiological synchrony and team adaptation, hypotheses were built upon team constructs underlying team adaptation. Specifically, in each of the modalities, existing literature indicated positive relations between team constructs underlying team adaptation and physiological synchrony. Results in the current study suggest that these relations cannot simply be, one-to-one, extrapolated to a relationship between team adaptation and physiological synchrony. This indicates that, when building the hypotheses, crucial relationships between team adaptation constructs and physiological synchrony might have been overlooked, while others might have been less translatable to the more comprehensive relationship between team adaption and physiological synchrony than was initially thought. This is also in line with existing literature on team adaptation (e.g., Burke et al., 2006), where it is suggested that each construct underlying team adaptation in itself does not necessarily result in adaptive behavior: it is rather a combination of constructs that is needed for teams to be adaptive.

In all, it remains unclear after the current study how, exactly, team adaptation and physiological synchrony relate to each other and what constructs play a role in this relationship. As is in line with other results in existing literature on physiological synchrony (Palumbo et al., 2017), the current study underlines the ambiguity of results in this field of research and illustrates that no definitive patterns can yet be established on relationships between physiological synchrony and team constructs.

Effect of the Unexpected Event

Two-way ANOVA analyses on physiological synchrony measures reveal that, in some modalities, significant results were found for effects of condition and level, thereby indicating that being in either the experimental condition or control condition, or going from the second level in the game to the third level, had an impact on levels of physiological synchrony, independently from the unexpected event. The interaction effects between condition and level, however, reveal non-significant results in all modalities, indicating that the unexpected event did not affect levels of physiological synchrony. Moreover, Welch's independent t-test on team adaptation scores reveal no statistically significant differences between the experimental condition and the control condition. This is interesting as it was hypothesized that these effects would be negative in nature, that is, decreased levels of physiological synchrony and team adaptation scores due to the unexpected event. A possible explanation for this finding may lie in the design of the experiment and the point in time where the intervention took place. The intervention was placed in-between the second and the third level in the game. As described in the *method* section, these two levels were considerably different in terms of level design and level difficulty, with the third level being more difficult than the second. Research has shown that task difficulty can affect levels of synchrony (Hadley & Ward, 2021; Mitkidis et al., 2015; Park et al., 2022) and subjective perceptions (Mitkidis et al., 2015), and it is possible that the same effects occurred in the current study when going from the second level to the third level, as results on the main effect of level indicate. Taken into account that teams in the experimental condition, on top of the increased level difficulty, also experienced partial membership loss, it is possible that the effect of the unexpected event was blurred out. As such, the design of the current study might not have been suitable for capturing the standalone effect of the unexpected event, and, therefore, results may not reveal the actual effect of an unexpected event on physiological synchrony and perceived team adaptation.

8 IMPLICATIONS

The current study poses several implications. First of all, this study is, to the knowledge of the author, the first one that assesses the direct relationship between physiological synchrony and team adaptation. As such, it builds further upon literature on team constructs and physiological synchrony, and extends this field of research by doing so. In contrast to what was expected from existing literature, no evidence was found for a positive relationship between physiological synchrony and team adaptation. In fact, the symbolic entropy and MdRQA measure reveal that these measures, in some modalities, negatively, instead of positively, relate to team adaptation. This shows that results of studies on team adaptation constructs and physiological synchrony cannot simply be extrapolated to the comprehensive relationship between team adaptation and physiological synchrony, and stresses the complexity of the effects of synchrony on team adaptation. As such, it keeps the conversation going about how physiological synchrony, exactly, relates to team constructs and how teams can benefit from it.

It should, however, be noted that each synchrony measure in this study captured different aspects of synchrony. In fact, both symbolic entropy and MdRQA, when diving deeper into their characteristics, should (potentially) be interpreted as a measure of regularity rather than synchrony in the strict sense. This might explain the found relationships and differences in results among measures in this study, and raises the question whether results on physiological synchrony in existing literature can be generalized when synchrony is computed with different measures. After all, as different measures capture different aspects of synchrony (or even regularity), relationships between team constructs and physiological synchrony can differ with different synchrony measures. Moreover, it stresses how important the role of the chosen synchrony measure is when studying relationships between team constructs and physiological synchrony.

By including an intervention, this study is the first one to investigate the effect of such intervention on levels of physiological synchrony. Although the effect of the intervention in the current study might have been blurred out by other, coinciding, changing variables, this study extends on existing literature by showing that such interventions can be used in the context of physiological synchrony and, as such, it lays a foundation for further research.

Whereas a vast majority of existing literature studied physiological synchrony in dyads, or in teams on the dyadic synchronization level (Palumbo et al., 2017), this study focused on group-level synchrony. Results reveal that group-level physiological synchrony in the current study did not necessarily emerge from cooperative contacts. In itself, this finding is not new, however, it illustrates the complexity of studying physiological synchrony and the conditions under which it emerges. Nevertheless, this study contributes to the scarce amount of research that has been conducted on physiological synchrony within teams and it shows how teams synchronize on the cardiovascular, electrodermal and motor level during a collaborative gaming task. By doing so, this study can be used to construct a more complete picture of physiological synchrony in general, and the conditions and interactions under which it emerges.

Overall, this study serves as another piece in the puzzle of understanding physiological synchrony and its relationship with team constructs. Results underline the ambiguity of this field of research and show that no definitive patterns have emerged yet. By studying physiological synchrony within three different modalities, computed by three different measures, this study contributes to existing literature and lays a foundation for studying physiological synchrony and its relationship with team adaptation more thoroughly.

9 LIMITATIONS

This study posed several limitations that should be considered when applying and generalizing the results. First of all, the experiment in this study was held in an online collaborative game play environment. As such, interactions patterns between team members may have been different from interaction patterns in face-to-face settings and, therefore, results of the current study may not be transferrable to face-to-face settings.

Another limitation was the limited amount of teams in the current study due to bad data. Results reveal a lot of non-significant effects, which might have been significant when the sample size of correctly captured teams would have been higher. Also, team attributes, such as the average gaming experience of team members, were not taken into account when doing the analyses. Such attributes might have had an influence on the results, which is not accounted for in the current study.

With respect to the study design, this study was limited by the fact that there was only one questionnaire on perceived team adaptation, which was held after the third level. It might have been more appropriate if the same questionnaire was also held before third level. In other words, one questionnaire on team adaptation before the intervention, and one after. Comparing results of these questionnaires might have provided more insights in the effect of the unexpected event on perceived team adaptation.

Finally, this study was limited by the fact that the second and the third level in the game were considerably different in terms of level design and level difficulty. As such, the actual effect of the unexpected event might have been blurred out and results may not reveal the actual effect of an unexpected event on physiological synchrony and perceived team adaptation.

10 FUTURE RESEARCH

From the current study and its results, several directions and recommendations arise for future research. First of all, future research may want to build upon the current study and investigate the relationship between physiological synchrony and team adaptation more thoroughly. To that end, it is recommended to study relationships between team adaptation constructs and physiological synchrony more in detail and investigate how these relationships relate and contribute to the bigger, comprehensive relationship between team adaptation and physiological synchrony. Such research should also include various methods to capture synchrony, such as capturing synchrony over smaller segments of time or focusing only on peak levels of synchrony. Doing this allows for capturing physiological synchrony more thoroughly, which may provide novel and unexpected insights in the relationship between team adaptation and physiological synchrony, and what factors influence that relationship. Furthermore, it is recommended to investigate the above mentioned relationships within different environments, such as face-to-face settings or hybrid settings, to investigate how the found relationships hold within such environments. It is also recommended to investigate relationships on a larger sample size than the current study did to account for non-significant results due to too little data.

Another direction for future research could be a further analysis of the effect of an unexpected event. The current study included an intervention where an unexpected event was simulated, and analyzed how that intervention affected levels of physiological synchrony and team adaptation. As the current study posed several limitations to that end, it is recommended to analyze the effect of such intervention within an environment that addresses the limitations of the current study. As such, it can be investigated whether an unexpected event, indeed, does not have an influence on levels of physiological synchrony and perceived team adaptation as the results in this study suggest.

Finally, it is recommended to gain deeper understanding of the concept of physiological synchrony itself. This study used several measures to compute levels of synchrony and results show that these measures do not always relate with each other, indicating that they capture different aspects of synchrony. Future research should focus on these differences between measures to investigate, in-depth, how synchrony measures relate with each other and what aspects of synchrony each of the measures captures. Furthermore, it was shown that physiological synchrony in most modalities and measures in this study did not necessarily emerge from cooperative contacts and could have been the result of matched dependence on external variables. Future research should dive deeper into such results and investigate how, exactly, synchrony is driven in different contexts. After all, synchrony driven by external variables may provide biased results when one is interested in interpersonal dynamics.

Finally, when studying physiological synchrony within groups of three or more people, it is recommended to combine group-level synchrony methods, such as used in this study, with dyadic-level synchrony methods to further investigate how synchrony between dyads contribute to overall group-level synchrony. Such way of computing physiological may provide novel insights as measuring synchrony as a system-level construct (i.e., the approach in this thesis) may not be the same as an aggregation of the synchrony between component dyads.

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