MASTER THESIS

SYNCHRONY IN HEARTBEAT: EXPLORING PHYSIOLOGICAL CO-OCCURRENCE DURING COLLABORATIVE ACTION OF POLICE-TEAMS

Janine Brinkmann

Educational Science and Technology,
Faculty of Behavioural, Management and Social Sciences,
University of Twente

Supervisors:
Dr. A. M. G. M. Hoogeboom-Hendriksen
Dr. I. Friso-van den Bos
Msc. L. Z. David

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UNIVERSITY OF TWENTE.

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Abstract

In police, action teams are tasked with ensuring public safety under high-stress and rapidly evolving, unpredictable situations. Previous research has shown that effective collaboration and coping with stress are essential for high team performance. However, the understanding of how they coordinate their actions during moments of high-stress on a team-level is limited, as research on simultaneously capturing their interactions and stress level is rare. This study used a multimodal design to capture police team members' co-occurrence of physiological stress and coordinative actions during collaboration in a virtual reality setting. Sociometric badges were used to measure their behaviour and stress level based on the heart rate variability to analyse physiological co-occurrence between team members. In total, four police teams of ten police officers participated, and physiological co-occurrence between four dyads within their teams was calculated. Results of this exploratory study revealed that moments of physiological co-occurrence occurred in all four teams, but the frequency and duration of these moments varied among these teams. Second, we examined when moments of co-occurrence happened and revealed patterns in stress levels and circumstances surrounding these moments. Third, we found that in moments of high co-occurrence, teams engaged in a wider variety of coordinative actions, while in moments without co-occurrence, they shifted their attention from the team to the suspect by demonstrating the de-escalation behaviour emphasising humanity. In addition, we found that teams consisting of two team members shared more physiological co-occurrence than teams of three. Fourth, we identified one team as more effective and three as less effective but did not find a significant difference in their amount of physiological co-occurrence. Overall, our study provides evidence supporting the significance of physiological co-occurrence within police teams and enriches our comprehension of the emergence of physiological co-occurrence based on the theories of cognitive appraisal and emotion contagion. Stress appraisals experienced by police team members extend beyond the individual level and are transmitted during moments where coordination is necessary. Additionally, our results suggest that when police team members redirect their focus away from their own team, their physiological signals become more distinct, aiding in improved communication and de-escalation with suspects. Our study demonstrated that virtual reality is a promising method not only for training purposes of police but also for research purposes for fine-grained investigations of complex and multifaceted collaboration processes during high-stress circumstances. This work revealed initial insights and patterns, but further research with a larger sample is needed to fully understand the complexity of these processes under stress.

Keywords: multimodal, collaboration, coordination, stress, police teams, physiological co-occurrence, team behaviour, emotion contagion, cognitive appraisal

Table of contents

Abbreviations

AAR	After action review
CLC	Closed-loop-communication
EDA	Electrodermal activity
HR	Heart rate
HRV	Heart rate variability
VR	Virtual reality
Zephyr	Medtronic Zephyr Bioharness 3.0

Introduction

Action teams, including police teams, must skilfully function within environments characterised by uncertainty, rapid pace, and intense stress (Giessing, 2021). The fundamental challenge for police teams is to maintain successful collaboration with the team through effective coordination of their actions within constant high-stress circumstances that are inherent to police work (Meier et al., 2007; Renden et al., 2015). To enhance the effectiveness of such teams, it is necessary to acquire a more detailed understanding of how they operate under high levels of stress and how this impacts their coordinative actions (Uitdewilligen & Waller, 2018). However, despite the significance of this topic, our understanding remains limited due to a lack of research that simultaneously captures team member's behaviour and physiological stress levels while also examining the emergence of these factors over time by adopting a fine-grained approach (Dindar et al., 2022; Schneider et al., 2020).

Studies examining teams operating in constantly changing high-pressure environments have uncovered relevant behaviours. For example, specific de-escalation techniques are employed by police teams when engaging with individuals in potentially violent situations, such as questioning techniques, emphasising humanity and honesty, and using verbal force to peacefully resolve dangerous situations (International Association of Chiefs of Police, 2020; Todak & James, 2018; Todak & White, 2019). Additionally, successful collaboration within teams is stimulated by a set of closed-loop-communication behaviours: mutual performance monitoring, back-up behaviour, and adaptive teamwork (Burke et al., 2006; Espevik et al., 2022; Salas et al., 2005). However, most of this research focuses only on the behavioural aspects, which leaves us with an incomplete understanding of how they maintain effective coordination under highly stressful situations. This is notable, as collaboration is defined as a multi-faceted construct encompassing behavioural, cognitive and emotional facets and years of research in psychophysiology have confirmed that human cognition is closely intertwined with the body (Critchley et al., 2013; Schneider et al., 2021). One way to gain a more comprehensive understanding of how team members coordinate their actions during stress is to take a multimodal approach (Dindar et al., 2022; Schneider et al., 2021). In the literature, we see more and more calls for incorporating behavioural and physiological measurements to understand how people react to stress or how it influences their collaboration processes (Haataja et al., 2018; Schneider et al., 2021). Recent technological developments such as virtual reality (VR) and wearable sensors provide data-capturing devices enabling this multimodal investigation into how such teams coordinate their actions under stressful circumstances.

An intriguing and emerging aspect in this regard is the concept of physiological co-occurrence, which refers to the interdependency of physiological processes, such as stress, among team members (Palumbo et al., 2016). Based on the cognitive appraisal theory, stress at the individual level occurs when a person perceives an imbalance between the demands of their situation and their individual resources to cope (Folkman et al., 1986). In this regard, scholars suggest that on the team level, stress emerges when members appraise their current situation alike (S. Liu & Liu, 2018). On the other hand, some scholars posit that, in line with the theory of emotion contagion, the stress reactivity of one team member can transmit to another, especially during interactions that express their stress reactions verbally or non-verbal (Barsade, 2002; Sassenus et al., 2022). However, a lot of research in the field of cognitive appraisal and emotion contagion is cross-sectional and based on subjective measurements of emotions and behaviour, which limits our understanding of how stress emerges and forms in teams (Herrando & Constantinides, 2021; Sassenus et al., 2022). Exploring how physiological co-occurrence emerges requires a temporal perspective and objective physiological measurements of team members' stress and fine-grained team behaviours. This multimodal approach would enrich the field of cognitive appraisal and emotion contagion and its potential interplay to explain the emergence of physiological co-occurrence by exploring how and which contextual factors can be related to shared stress and how stress might be transmitted through interactions.

Furthermore, this approach would offer valuable insights into the potential effects of physiological co-occurrence on team performance. On the one hand, research indicates that stress on the team level can hinder team performance by impeding information processing and effective adaption (Dietz et al., 2010). Conversely, some scholars propose that team stress can benefit team performance by fostering rapid decision-making and cognitive functioning (Baldwin et al., 2019; Nieuwenhuys & Oudejans, 2011; Sassenus et al., 2022). In this regard, current findings indicate that physiological co-occurrence of arousal among team members relates to various critical team performance aspects, such as mutual understanding (Järvelä et al., 2015), team performance (Dich et al., 2018; Henning et al., 2009) or collaborative problem solving (Dindar et al., 2022). These insights suggest that team members make their thoughts, ideas and arguments explicit and negotiate strategies to solve conflicts during moments of physiological co-occurrence (Dindar et al., 2022). However, studying and comparing team behaviours during moments of physiological co-occurrence and outside these moments would allow a better interpretation of how physiological co-occurrence can be related to team performance.

This study contributes to the extant literature in at least three ways. Firstly, it pioneers the integration of physiological stress measures and team behaviour within a police context using VR as a multimodal tool. By doing so, we can address how stress accompanies police team members' coordinative actions during collaboration. Secondly, our focus is on exploring physiological co-occurrence in such teams by analysing when moments occur and how team members behave during and outside these moments, which allows us to drive our understanding into the emergence of physiological co-occurrence. Thereby, we enrich the fields of cognitive appraisal and emotion contagion with objective and multimodal measurements to see how these processes play out in time and interplay with each other. Thirdly, this research examines how physiological co-occurrence relates to team performance by considering team members' behaviour. Thus, the study contributes to the limited insights into the potential effects of physiological co-occurrence.

Theoretical Framework

Police teams

Teams are a distinct groups of two or more individuals working interdependently towards common goals (Salas et al., 1992). Action teams are a specific type of team in which team members coordinate their actions in intense and unpredictable situations that require a high degree of expertise and rapid decision-making (Edmondson, 2003). Thus, these teams often operate in settings where high-stakes and time-sensitive activities are needed, such as emergency response, crime or military operations (Ishak & Ballard, 2012).

This study focuses specifically on police teams, which are tasked with ensuring public safety, enforcing laws and investigating crimes (Giessing, 2021). In many cases, police teams are called upon to respond to unpredictable, complex, highly stressful and rapidly evolving situations in the line of duty (Gershon et al., 2009; Giessing, 2021). For example, police officers involved in a domestic violence incident face a variety of demands. They are required to quickly assess the context of the situation; evaluate the risk of danger for the team and others; communicate with incident command, the possible perpetrator, the victim, and each other; and make decisions about appropriate interventions (e.g. use of force, arrest, medical care, etc.) (Kleygrewe et al., 2023). The nature of police work can lead to high levels of physiological arousal as a natural response to stress, particularly in situations involving high-risk activities such as responding to an active shooter, apprehending a dangerous suspect, or negotiating with a hostage taker (Nieuwenhuys & Oudejans, 2011; Renden et al., 2015). In these situations, optimal task performance is required, as failure can have enormous consequences for police officers themselves, colleagues, suspects or innocent bystanders (Giessing, 2021). Previous literature suggests that effective collaboration is a key driver to successfully resolve high-pressure situations but is also particularly challenging because of the tendency for people to narrow their focus under stress. Consequently, cognitive function and decision-making abilities become impaired, posing challenges in exploring alternative perspectives for solving complex problems (Di Nota et al., 2021; Driskell et al., 1999; Kazi et al., 2021). Hence, one of the biggest challenges for police teams is to successfully keep coordinating their actions even in the high-stress circumstances of police work (Meier et al., 2007; Renden et al., 2015).

Police de-escalation behaviour

In order to protect and keep civilians safe, police teams are required to use appropriate force to effectively control incidents while protecting their own safety and the safety of others. Thereby, police officers are called to use only the force that is objectively reasonable to effectively gain control over an incident (International Association of Chiefs of Police, 2020). To achieve this, they use de-escalating behaviours to act or communicate during potential violence in an attempt to stabilise the situation and reduce the immediacy of the threat, thereby creating additional time, options and resources to resolve the situation peacefully and minimise harm (International Association of Chiefs of Police, 2020).

When de-escalation techniques are not effective or appropriate, an officer is authorised to use less-lethal force techniques and equipment to bring a situation safely under control (International Association of Chiefs of Police, 2020). At the first level, police officers are trained to de-escalate a situation by using *questioning techniques* to gather information and converse with the person. Open-ended questions are used to get detailed answers and allow the person to speak freely. They help officers to assess the person's reality and gather information. Closed questions, on the other hand, are used to get simple "yes" or "no" answers or specific information. They can help to get commitments and gather the necessary details. Here, active listening is crucial as it allows officers to maintain control, listen carefully to what the person is saying, develop empathy and ultimately resolve the situation safely and effectively (Oliva et al., 2010). Police officers are required to maintain a calm demeanour and focus on *emphasising their human qualities* rather than relying solely on official authority to reduce the power imbalance between police officers and citizens, such as showing emotion, treating people with dignity and respect, and avoiding authoritarian or condescending behaviour (Todak & James, 2018; Todak & White, 2019). In addition, by utilising *honesty* as a strategy, police officers can establish mutual understanding and cooperation with citizens by clearly explaining their objectives and guidelines (Todak & White, 2019). In some cases, attempts to employ these techniques prove ineffective or cause a dangerous delay jeopardising the officer's or others' safety, resulting in evidence destruction, suspect escape, or the commission of a crime. In this case, officers may resort to issuing *verbal use of force*, including commands, prompt advisements or warnings before employing less-lethal force techniques (e.g. the use of weapons) to gain control over a situation. Hence, officers can deliver calm and non-threatening commands or escalate their volume to elicit compliance (International Association of Chiefs of Police, 2020).

Research investigating police de-escalation behaviour and use of force has indicated that the level of threat presented by the subject serves as a predictor of force, as it is related to the officer's perception of risk and determines whether an officer escalates from using a calm tone of voice to verbal commands (James et al., 2018; Todak & James, 2018). Todak and James (2018) observed the use of de-escalation techniques by police officers through systematic social observation and found that officers avoid escalating situations in general by adopting a respectful tone most of the time and making an effort to emphasise humanity in order to speak to citizens as people rather than suspects or subordinates. 70% of the time, officers employ the technique of honesty to help citizens comprehend their perspective. Handcuffing was observed as the most severe measure utilised. The findings of their study indicate that these different techniques serve as natural tools for fostering effective communication with others. Moreover, these techniques helped officers resolve situations peacefully, even in situations with potential conflict. Their findings align with additional research suggesting that de-escalation techniques promote conflict resolution by employing minimal force and can also serve as preventive measures (Engel et al., 2022; Terrill, 2005; Todak & White, 2019).

When police officers enter a de-escalation phase, it becomes crucial for all officers involved to reach a consensus on the appropriate course of action. Thus, the responsibility for determining the reasonableness of the chosen approach rests on the collective shoulders of the whole police team (International Association of Chiefs of Police, 2020; Todak & White, 2019). Effective collaboration within the team is vital to achieve the desired outcomes successfully and resolve any conflicts that may arise along the way.

Coordinative actions during collaboration

Collaboration is defined as the joint effort of all team members towards achieving the group's goal, which requires coordination of individual efforts due to the complex and interdependent nature of collaborative activities (Kolfschoten et al., 2010; Meier et al., 2007). Team coordination is described as "orchestrating the sequence and timing of interdependent actions" (Marks et al., 2001, p. 363). These actions among team members are vital in defining goals, fostering commitment, and aligning behaviours toward goal achievement. Thus, we use the term coordination in our study to refer to team members' coordinative actions as a means to collaborate effectively. These coordinative actions are continuous processes that occur over time, and they can happen either implicitly or explicitly without explicit request (Stachowski et al., 2009; Wiltshire et al., 2022).

In complex environments, such as when apprehending an armed perpetrator while ensuring the safety of civilians, effective collaboration becomes increasingly important (Espevik et al., 2022). In such situations, police team members need to continuously share information to update their understanding of the evolving situation, which allows them to coordinate their actions and collectively determine the next steps for effective response (Uitdewilligen & Waller, 2018). Previous studies in action teams highlight specific actions for facilitating knowledge sharing, attention direction and determining future steps (Cooke et al., 2007; Stachowski et al., 2009). Research indicates that effective action teams exhibit specific interaction patterns in critical situations, including fewer verbal statements and less back-and-forth communication (Lei et al., 2016; Stachowski et al., 2009). Instead of lengthy explanations, teams prioritise efficient information exchange to address these situations as effectively as possible. In this regard, a set of behaviours has been identified as effective in managing dynamic and high-pressure situations: closed-loop-communication (CLC), mutual performance monitoring, back-up behaviour and team adaption. These four behaviours are based on the teamwork model by Salas et al. (2005) and applied in the context of police teams (Espevik et al., 2022). To allow for observing and coding these behaviours in a fine-grained manner, Lei et al. (2016) offer a coding scheme rooted in earlier work on action teams working in dynamic contexts (Stachowski et al., 2009). The following section outlines the set of four behaviours to understand how police team members effectively interact with each other and explains their association with actual, observable behaviours based on our coding scheme adopted by Lei et al. (2016).

Closed-loop-communication

CLC is defined as exchanging information and coordinating actions through explicitly expressing feedback and response (Espevik et al., 2021). As such, CLC is a coordinating mechanism in police work, in which *information is transmitted, received and acknowledged* in a clear and structured manner to ensure a clear course of action (Espevik et al., 2022). It enables team members to quickly create a shared understanding that facilitates coordination and enhances decision-making quality in stressful situations (Cooke et al., 2000; Uitdewilligen & Waller, 2018). This three-step process involves providing information, confirming receipt, and confirming mutual understanding (Sonnenwald, 2006). For instance, when police team member A presents information about a crime scene to police team member B, B acknowledges the information by confirming it verbally back to A, and A verifies that the message has been received and correctly interpreted (Sonnenwald, 2006). In this way, a loop is created to ensure a common understanding. This kind of communication among teams is often implicit, meaning information exchange occurs without explicit requests (Schraagen & Rasker, 2001). By continuously sharing information this way, teams minimise misunderstandings, reduce errors and enhance their coordination, as they are aware of the shared knowledge that serves as input for their collaborative efforts (Clark & Brennan, 1991; Sonnenwald, 2006; Uitdewilligen & Waller, 2018). Accordingly, studies on medical action teams found that CLC was negatively associated with the number of critical incidents and medical errors and positively associated with increased working speed and team efficiency (El-Shafy et al., 2018; Lacson et al., 2016).

Mutual performance monitoring

Mutual performance monitoring is described as team members paying attention to the performance of other team members in parallel with their own behaviour (Espevik et al., 2022). Thereby, team members regularly *observe each other*, look for mistakes and performance discrepancies, and intervene promptly to correct their teammates (Burke et al., 2006). Communication plays a vital role in this process, as team members *share information* about the tasks they execute, give advice on what to do and provide feedback about each other's task performance (Schraagen & Rasker, 2001). The purpose of *monitoring* is to ensure the team's progress towards the goal and the accuracy of the performance (Espevik et al., 2022). Firstly, when team members offer each other feedback through *verbal suggestions* or corrective behaviour, they can rectify mistakes and enhance performance more easily by alerting team members to necessary adjustments (Burke et al., 2006). It is proposed that this information boosts the team from the sum of individual performance to the synergy of teamwork (Salas et al., 2005). Secondly, mutual performance monitoring allows team members to execute a plan as it promotes awareness of the timing and pace of their team members' actions (Kozlowski, 1998). Thirdly, it enhances their situational awareness so that team members can adjust their actions appropriately (Salas et al., 1995). Therefore, team members can pose commands to each other to adjust their actions, *suggest* alternatives, or state their *opinion* about the course of action. Accordingly, research has confirmed that mutual performance monitoring is a significant, positive predictor of team effectiveness (Lafond et al., 2011).

Back-up behaviour

Another essential aspect of effective collaboration is back-up behaviour, which involves team members mutually supporting each other when overloaded to ensure a balanced distribution of workload (Espevik et al., 2022). Back-up behaviour, as defined by Porter et al. (2003), refers to "*the discretionary provision of resources and task-related effort to another member of one's team that is intended to help that team member obtain the goals as defined by his or her role when it is apparent that the team member is failing to reach those goals*" (pp. 391-392). There are three ways team members can provide back-up behaviour: through *feedback and coaching* towards team members, *assisting* a team member in performing a task, or *fully completing* a task of a team member when an overload is detected (Marks et al., 2001). Mutual performance monitoring, as mentioned earlier, plays a vital role in *gathering information* that informs back-up behaviour. Therefore, team members do not only *observe* the situation or their team members' behaviour but also pose *questions* or *inquiries* to gather information or *answers*, *acknowledgements* or *expressions* to provide information. Team members use this information then to adjust their actions and address team issues (Burke et al., 2006). That means when a team identifies through mutual performance monitoring that a member's workload exceeds their capacity, the team can engage in back-up behaviours by redistributing work responsibilities to other team members, for instance, in the form of *commands* or *briefing* behaviours (Salas et al., 2005). Research has confirmed the positive impact of back-up behaviour on team performance in the context of police teams, as it enhances team processes and facilitates adaptation to environmental changes (Espevik et al., 2022).

Team adaptation

Another critical attribute of effective collaboration is team adaption, which is the ability to recognise deviations from expected actions and readjust actions accordingly (Priest et al., 2002). To maintain adaptability, teams require a shared understanding of their task, awareness of how changes may impact team members' roles in the team task, and the ability to *recognise* when changes are occurring (Salas et al., 2005). As such, similar to performance monitoring and back-up behaviour, team members remain vigilant in the activities of other team members to detect errors and determine if *additional information* or assistance is needed (Salas et al., 2005). Therefore, team members constantly assess changes in the environment or the task by *observing* the situation and *briefing* each other on what to expect in the next situation to ensure that they will reach the team's goals with the current course of action (Salas et al., 2005). In addition, they gather information through *questioning* and *inquiring* and provide information to each other by posing *answers*, *acknowledgements* or *expressions.* These behaviours allow teams to adapt quickly and respond to unexpected demands, such as during an armed robbery. Teams must identify cues indicating changes in conditions (e.g. time allotted to complete the task), make sense of these changes (e.g. requiring a shift in strategy), and develop and execute new action plans successfully. Skipping or mishandling any step in this process reduces the team's chances of success (Salas et al., 2005).

Particularly police teams, who work in dynamic and stressful situations, need to adapt quickly and accordingly to find the best solution (Espevik et al., 2022; Uitdewilligen et al., 2018). Therefore, the question remains how they maintain adaptability and coordinate their actions during these stressful moments. Stress plays an essential role in police team interactions as the forms of nonverbal communication triggered by certain emotional states influence team decisions and interactions (Le Dantec & Do, 2009; Schneider et al., 2021). The bidirectional relationship between emotion, behaviour and cognition means that mental states are reflected in physiological signals, and conversely, bodily physiology influences human consciousness and cognition (Haataja et al., 2018; Schneider et al., 2021). Consequently, it is not only interesting to measure team behaviour in isolation but also to consider other physiological parameters, particularly team members' physiological arousal, to understand how they coordinative their actions during moments where they experience stress.

Physiological arousal

When confronted with a threatening stimulus, the body engages in a series of automatic physiological processes (LeDoux & Pine, 2016). These processes result in physiological responses such as increased blood pressure and respiration rate, collectively known as *physiological arousal* (American Psychological Association, n.d.). Changes in these physiological signals are connected to emotional or mental states, such as stress levels (Brisinda et al., 2015; Laborde et al., 2017) and excitement (Russell, 1980). Therefore, an increase in physiological arousal is not solely associated with distress but can also indicate positive psychological states, that is, eustress (Endedijk et al., 2018). However, Eysenck et al. (2007) state that when individuals have to perform in high-anxiety situations, their attention is drawn towards threat-related sources of information. Thus, in concordance with further studies in the context of police teams, we interpret high levels of arousal as an indicator of feelings of distress (Brisinda et al., 2015; Kleygrewe et al., 2023; Zechner et al., 2023).

Markers of physiological arousal are, for example, heart rate variability (HRV), blood pressure or electrodermal activity (EDA) (Boucsein, 2012; Hoogeboom et al., 2021; Kazi et al., 2021). Our analysis specifically focused on HRV, which is a promising method, as it is a simple, non-invasive, real-time analysable and highly reproducible measurement (Gancitano et al., 2021). However, it is important to note that HRV can be affected by artefacts and distortions caused by physical activity or movement, such as walking or sweeping arm movements (Giessing, 2021). Nevertheless, studies have demonstrated the feasibility of measuring ambulatory HRV while simultaneously monitoring breathing and physical activity (Baldwin et al., 2019; Laborde et al., 2017). Further, HRV parameters have shown the ability to distinguish between rest and stress conditions, as well as mental and physical stress during various high and medium-stress realistic police scenarios (Brisinda et al., 2015). The autonomic nervous system, specifically the sympathetic and parasympathetic branches, regulates heart rate (HR), with the parasympathetic system decreasing HR and increasing HRV, while the sympathetic system increases HR and decreases HRV. During rest and recovery, HR is at its lowest, and HRV is at its highest, whereas stressful situations increase sympathetic activity, resulting in elevated resting HR and decreased HRV (Gancitano et al., 2021). Overall, HRV reflects an individual's ability to effectively organise physiological and behavioural resources in response to environmental demands. HRV is related to cognitive functions such as memory, cognitive control and attention (Siennicka et al., 2019; Thayer & Lane, 2000). Thus, higher resting HRV allows for faster adaptation and greater behavioural flexibility in challenging environments, whereas individuals with low HRV may have a reduced ability to respond effectively (Gancitano et al., 2021; Giessing, 2021). HRV has also been used in previous research to assess the individual stress response of police officers (Baldwin et al., 2022; Bertilsson et al., 2020; Kleygrewe et al., 2023). Due to the diverse work stressors that police officers encounter, which require a wide range of behavioural responses, HRV has emerged as an objective method to assess the extent of police officers' mental effort accurately (Giessing, 2021). Moreover, studies on heart rate variability (HRV) training interventions have shown promising results in reducing stress responses among police officers (Andersen et al., 2015; Anderson et al., 2019; Arnetz et al., 2013).

Stress and police performance

The impact of stress on police performance is a complex phenomenon. Based on the cognitive appraisal theory, stress arises when individuals perceive that their coping resources are insufficient to meet environmental demands (Folkman et al., 1986; Vine et al., 2016). These stress responses influence cognition and behaviour by shifting attention from goal-directed to stimulus-driven control (Eysenck et al., 2007). This automatic fight-or-flight response is below conscious awareness and is a default human response to ensure survival (LeDoux & Pine, 2016). On the one hand, a stress level that matches the demands of the situation can be beneficial for optimal performance during threatening situations. It can enhance sensory perceptions, facilitate rapid decision-making, and improve cognitive functioning (Akinola & Mendes, 2012; Baldwin et al., 2019; Nieuwenhuys & Oudejans, 2011). On the other hand, maladaptive stress, which can be seen as too high or too low, results in impaired police performance (Baldwin et al., 2019; Vine et al., 2016). It can lead to increased task errors, reduced task accuracy, and negative effects on cognitive functions such as attention, perception, and decision-making (Baldwin et al., 2019; Driskell et al., 1999). One explanation is limited information processing capacity, which makes it difficult to pay attention to two things simultaneously, and a restricted perceptual field so that individuals fail to notice relevant cues (Baldwin et al., 2019). Additionally, maladaptive stress is associated with impulsive, disorganised, and inefficient behaviour, characterised by hypervigilant decision-making (Johnston et al., 1997). Haller et al. (2014) found a link between maladaptive HR arousal and aggressive behaviour exhibited by police officers in critical situations. Overall, the effects of stress can be particularly detrimental for police teams during critical incidents and might severely impact their coordinative actions during a crisis. However, research in this area is limited, and an important question remains whether an optimal range of stress exists for optimal performance (Baldwin et al., 2019; Baldwin et al., 2022).

Research suggests examining stress at the team level to understand this mechanism by explicitly investigating the co-occurrence of physiological stress among team members (Malmberg, Haataja, et al., 2019; Palumbo et al., 2016; Sassenus et al., 2022). This approach is becoming increasingly promising as the influence of stress between team members plays a significant role, particularly in their interactions. As such, Sassenus et al. (2022) argue that team members' stress can become shared and intensified as they display similar behavioural, physiological, cognitive and emotional responses.

Co-occurrence of physiological stress

Research has demonstrated that emotional states can synchronise among individuals involved in interactions occurring at various levels, such as behaviour, neural activity, and physiological responses (Behrens et al., 2020). Palumbo et al. (2016) define physiological co-occurrence as an interdependent or associated activity identified in the physiological process of interacting individuals. This suggests an observed association (or interdependency) between team members' physiological processes, reflecting the connections between people's continuous measures of autonomic nervous systems. When teams operate in the same context, physiological arousal among team members can be dependent and can co-occur among team members during collaboration (Malmberg, Haataja, et al., 2019). The exploration of physiological co-occurrence initially focused on dyads in clinical settings, particularly therapist-client interactions, to study therapeutic rapport and empathy (Marci et al., 2007; Palumbo et al., 2016; Snijdewint & Scheepers, 2022). Subsequently, this concept has been extended to various other contexts, including couples, parent-child relationships and teams (Palumbo et al., 2016). While work on couples primarily examined the effects of co-occurrence on marital conflicts (Gates et al., 2015; Palumbo et al., 2016; Reed et al., 2013), parent and children investigations focussed on investigating the relationship between co-occurrence and self-regulation or psychological health (Palumbo et al., 2016; Suveg et al., 2016). Studies on teams focussed particularly on measuring physiological co-occurrence between dyads (Palumbo et al., 2016). For instance, Haataja et al. (2018) analysed the level of synchrony among individual pairs within a group during the collaboration of students and associations with monitoring of cognition, behaviour and affect. In our study, physiological co-occurrence refers to the synchrony between the physiological responses of interacting police team members as they perform a collaborative task. As research on physiological co-occurrence within action teams is currently limited, we rely in the following on studies of teams in the context of collaboration and coordination in general. The primary physiological measure used in these studies is

HR and HRV (Behrens et al., 2020; Y. Liu et al., 2021), EDA (Behrens et al., 2020; Dich et al., 2018; Dindar et al., 2020; Dindar et al., 2022; Haataja et al., 2018; Schneider et al., 2020) interbeat-intervals (Tomashin et al., 2022) or cortisol (Denk et al., 2021). The physiological data is then used to calculate the physiological co-occurrence among team members by looking at the correspondence of their signals for multiple measurement points in time series data (Dindar et al., 2022). Popular methods used to calculate physiological co-occurrence among team members are Instantaneous Derivative Matching, Signal Matching, Pearson's Correlation or Directional Agreement (Dich et al., 2018; Dindar et al., 2022).

There are two viewpoints explaining the emergence of physiological co-occurrence during collaboration. The first is rooted in the theory of cognitive appraisal, suggesting that physiological co-occurrence is related to shared responses to external events (S. Liu & Liu, 2018; Palumbo et al., 2016). Thus, shared stress may result when police team members perceive a mismatch between the demands of the situation and their available resources (Folkman et al., 1986). The second viewpoint, prevalent in most research on physiological co-occurrence, stems from the theory of emotion contagion, proposing that individuals copy emotions and behaviour that they perceive from others during interactions (Barsade, 2002). That means stress reactivity is transmitted between police team members through their coordinative actions. Derived from this, an interplay of both viewpoints could indicate that when one team member perceives stress and transfers this reactivity, other team members may perceive their situation similarly, leading to aligned stress appraisals (Sassenus et al., 2022). Recent research indicates that self-disclosure, involving sharing perceptions and thoughts, can lead to positive group outcomes (Peiró, 2009; Sassenus et al., 2022).

However, the results on the effects of physiological co-occurrence on teams are inconsistent. On the one hand, Behrens et al. (2020) demonstrate that the strength of physiological co-occurrence in skin conductance level between two pairs during collaboration predicts their success. Y. Liu et al. (2021) also found that high-collaboration student pairs shared stronger physiological co-occurrence during group discussions than low-collaboration dyads. Montague et al. (2014) study on participants working in a computer-based collaborative setting found a positive relationship between the strength of physiological co-occurrence and group performance. Further studies found a positive relationship between the strength of physiological co-occurrence and monitoring in collaborative learning (Haataja et al., 2018). Additionally, research demonstrates that moments of physiological co-occurrence refer to moments of collaborative problem-solving (Dindar et al., 2022). Schneider et al. (2020) qualitative evidence suggests that moments of high physiological co-occurrence may be linked to joint responses to external events. They further found that successful teams switched between high and low physiological co-occurrence to a greater extent and indicated that levels of co-occurrence increase through collaboration and decrease by working independently. A recent meta-analysis supports the positive effect of physiological co-occurrence on group outcomes such as cohesion, commitment, and performance (Mayo et al., 2021). On the other hand, some studies have reported a negative relationship between physiological co-occurrence, measured by interbeat-intervals, and team cohesion (Strang et al., 2014) or the strength of physiological co-occurrence measured by HRV and effective team communication and teamwork in a research team (Henning et al., 2009). Interestingly, there are variations in the predictive power of different physiological measures, with some studies showing that physiological co-occurrence based on skin conductance measurements predicts cooperative success while HRV does not (Behrens et al., 2020).

Overall, the research field is still unclear, and the findings are contradictory. The results appear to be context-dependent and influenced by the physiological methods used. Further research with more fine-grained measurements into the emergence of physiological co-occurrence could help gain a more comprehensive understanding of the emergence and effects of physiological co-occurrence (Schneider et al., 2021; Sjøvold et al., 2022). Thus, exploring the exhibited behaviour over time becomes particularly intriguing to allow a better interpretation and a deeper understanding of physiological co-occurrence. Moreover, expanding these investigations to other contexts, such as action teams, holds great potential as this construct remains largely unexplored in such settings.

Simulation-based VR training

Under stress, critical behaviours such as shooting accuracy, self-defence, coordination, and communication can be impaired (Nieuwenhuys & Oudejans, 2011; Renden et al., 2015). To address this, action teams need training in realistic environments to master responses in stressful situations (Endedijk et al., 2018; Muñoz et al., 2020). However, formal training often fails to replicate realistic threatening situations, so it does not address training in high-stress situations as effectively as needed (Baldwin et al., 2022). One established method for training officers and replicating real-life incidents is VR, which immerses users in simulated environments, offering vivid visuals and interactivity (Steffen et al., 2019). It is increasingly utilised in training and education for action teams such as surgery, the military, aviation, and policing (Murtinger et al., 2021). It creates immersive scenarios that closely resemble real-life situations, including role-plays involving actors as perpetrators or victims, virtual objects and settings designed to replicate the actual scenario. By engaging in interactive and dynamic training scenarios, trainees can develop and execute verbal, cognitive, and physical skills simultaneously while exploring various behavioural strategies to handle complex situations (Nieuwenhuys & Oudejans, 2011; Zechner et al., 2023). Implementing the *Repeatedly Linked Stress Exposure* training approach, which repeatedly exposes police officers to stress similar to what they face on duty, helps them adapt to stress and potentially enhances their performance under such conditions (Kleygrewe et al., 2023; Nieuwenhuys & Oudejans, 2011). Nevertheless, Baldwin et al. (2019) findings indicate that individual variables such as officers' age, gender, years of experience or training experience do not impact their stress responses. Instead, stress responses are primarily associated with individual reactions to higher risk cues. In this regard, VR has been shown to successfully induce stress by cues such as a stranger suddenly walking into a room, a person holding a handgun, an injured person at a crime scene or an aggressively barking dog, and thus elicit corresponding psychophysiological responses (Giessing, 2021; Zechner et al., 2023). The main benefits of VR are that it allows for flexible scenario design and objective performance measures like reaction time, enabling trainees to review past scenarios and assess their effectiveness (Giessing, 2021). This adaptive feedback can influence and regulate team coordination patterns, ultimately enhancing future performance (Wiltshire et al., 2022). Additionally, providing police trainees with information about their stress levels using techniques like HRV biofeedback has effectively reduced stress and anxiety in real-life settings and VR environments (Goessl et al., 2017; Rockstroh et al., 2019). Overall, VR training offers a promising solution to replicate stressful scenarios in a safe and controllable environment, particularly in professions where mistakes can have severe consequences (Davies, 2015).

VR in research

In addition to its applications in training, VR is increasingly utilised for research purposes, offering opportunities to investigate social behaviour in ecologically valid environments with high experimental control (Giessing, 2021). Combined with wearable sensors, VR facilitates multimodal studies where data is collected over time and across multiple individuals. This enables researchers to capture rich, objective, multidimensional information to explore social interactions and behaviour over time (Schneider et al., 2021; Wiltshire et al., 2022). Wearable sensors can detect body signals and analyse behaviours without interfering with natural work processes, providing insights into how individuals and teams respond and interact (Endedijk et al., 2018). As such, they are valuable for studying speech and interaction patterns of individuals' and teams' structures (Kim et al., 2012), physiological states or body posture (Schneider et al., 2021) or detailed processes to look at team dynamics (Malmberg, Järvelä, et al., 2019) during collaboration. Such research allows for collecting valid data, facilitating the study of complex social phenomena. Many researchers advocate for further exploration in this area due to its potential (Noroozi et al., 2020; Schneider et al., 2021; Sjøvold et al., 2022). One notable project in the field of police teams is the European Horizon 2020 project SHOTPROS (SHOTPROS, n.d.), which focuses on understanding how psychological and contextual factors influence the decision-making and action-taking behaviour of police officers in high-stress and high-risk situations. The project aims to design improved training programs for police officers by developing a VR solution for conducting experimental assessments. Hence, this project not only enhances practical police training but also contributes to the emerging field of research in this domain.

Taking inspiration from multimodal studies conducted on police teams using VR, this research specifically concentrates on examining coordinative actions in combination with physiological co-occurrence over time in police teams in a VR environment. Thereby, we aim to explore how team members coordinate their actions under stress and how physiological co-occurrence emerges during the collaborative activity of police teams. Based on the theories of cognitive appraisal and emotion contagion, we examine how contextual factors are related to physiological co-occurrence and how physiological co-occurrence might be transmitted through team members' coordinative actions. Additionally, we explore the relationship between physiological co-occurrence and team performance to interpret its potential effects. By addressing the following main research question, we aim to contribute to a more comprehensive understanding of the emergence and effects of physiological co-occurrence: "*Under which circumstances does physiological co-occurrence among team members happen, and how do team members coordinate their actions during these moments*?". This research question can be divided into the following four sub-questions:

(1) How often do moments of physiological co-occurrence happen?

(2) When do moments of physiological co-occurrence happen?

(3) What coordinative actions occur in the team during moments of physiological co-occurrence, as compared to moments when no physiological co-occurrence is present?

(4) How can physiological co-occurrence be related to team performance?

Methods

Study Design

The present field study examines police teams' physiological co-occurrence and behaviour during collaboration in a VR setting. A multimodal design was applied that comprises two sources of data: (1) HRV measurements for the participating members through the Medtronic Zephyr Bioharness 3.0 (Zephyr) incl. classification of this data into low, medium and high stress to analyse physiological co-occurrence, and (2) minute video coding of the VR simulations to capture team members coordinative actions. This secondary data were provided by a tech company based in the Netherlands that offers virtual training solutions for action teams. Every team member voluntarily participated in the VR simulation and agreed to use the data for this study. The ethical review board of the University of Twente further approved the study (no 230225).

Participants

The secondary data includes nine police teams of twenty-two police officers operating in their natural team constellation and having experienced and completed VR training in September 2022. To answer the RQ of the study and identify moments of physiological co-occurrence, all teams with stress values from at least two team members per simulation were selected from these data, resulting in four police teams of ten police officers. An overview is depicted in Table 1. The team sizes varied between two to three team members, and team members were anonymised. Two participants were female (20%), and 8 were male (80%). The role of each member, age, and years of experience are unknown.

Table 1

Simulation and Participant Characteristics

Simulation	Duration	Team member	Gender	HRV data available
The arrest 1	665 seconds	T1	Male	Yes
		T2	Male	Yes
		T3	Male	-
The arrest 2	611 seconds	T4	Male	Yes
		T5	Male	Yes
The arrest 3	198 seconds	T6	Male	Yes
		T7	Male	Yes
		T8	Male	-
The confused person 1	534 seconds	T9	Female	Yes
		T10	Female	Yes

Note. Further, descriptive statistics such as age, years of experience and team role are unknown.

As presented in Table 1, these four teams participated in two kinds of simulation scenarios: *The arrest* and *the confused person*. The duration of the simulations ranged overall from 198 to 665 seconds (M = 502.0, SD = 209.67). In *the arrest* simulations, the teams had to search an apartment and search for suspects. In *the arrest 1* and *the arrest 2,* both teams completed the simulation successfully. The team of *the arrest 3* had to stop after arresting the first suspect due to the motion sickness of one team member. The duration of *the arrest* simulations ranged overall from 198 to 665 seconds (M = 491.33, SD = 255.46). The language for each simulation was English. In *the confused person 1* simulation, the team had to search an apartment and find objects, such as weapons or drugs, and a child and a suspect considering suicide. The duration of *the confused person 1* simulation was 534 seconds. The working language was Dutch.

Measurements

Physiological stress

Team members' physiological stress was assessed during the simulations as a continuous physiological measure using an adjustable onboard skin conductive electrode belt, the Zephyr (Gancitano et al., 2021). This device is capable of real-time and long-distance recording of various physiological parameters, such as the HRV, respiration, body temperature, movement, one-lead electrocardiography, and the estimated V02max (Gancitano et al., 2021). Figure 1 shows a picture of this device.

Figure 1

Component Parts of the Medtronic Zephyr Bioharness 3.0

Note. Picture and components of the physiological monitoring device. Adapted from *HRV in active-duty special forces and public order military personnel*, by G. Gancitano, 2021, *Sustainability*, *13,* p. 4. Copyright by Zephyr Technology Corporation.

Our analysis focussed particularly on the HRV. Average and maximum HR in beats per minute were recorded at a recording frequency of 1 Hz (Zephyr™ Technology, 2016). Good to excellent quality evidence suggests that the Zephyr can provide reliable and valid HR measurements across multiple contexts, such as in healthy, clinical or athletic populations (Nazari et al., 2018). The Zephyr has been applied in previous work in the context of police teams for using HRV measurements as a parameter to assess police officer's cardiovascular responses to stress (Bertilsson et al., 2020; Kleygrewe et al., 2023; Zechner et al., 2023). However, in this study, due to the limited availability of Zephyr budgets, HRV data are not available for each participant (see Table 1).

To assess each team member's stress level in real-time, a machine learning algorithm using the RMSSD method has been applied. This algorithm compares 30-second moving average intervals of HR and HRV to the trainee's individual baseline during the training and weighted stress scores accordingly (Laborde et al., 2017; Zechner et al., 2023). The resulting values are classified into low, medium and high-stress, with missing values represented in a grey colour. The collected HRV signals are transferred via Bluetooth from the Zephyr into the After Action Review (AAR) Software so that the resulting values are visualised in a panel in the system (see Figure A1 and A2 in Appendix A).

Team member behaviour

The VR simulations were used to capture team members' coordinative actions. The simulations were stored and visible through the AAR Software, which enables the 3D view of the simulation, including the vision of the simulation (e.g. objects and people in the environment), the audio sound of the simulation (e.g. team members speaking, dogs barking), and special functionalities for reviewing. These functionalities include switching between the bird's eye view or the perspective of individual persons and the walking track of the person on or off (see Figure A3 in Appendix A).

A pre-specified codebook was used to code behavioural utterances that are related to the coordinative actions of CLC, mutual performance monitoring, back-up behaviour and team adaption. The fine-grained codes are based on validated codebooks that are rooted in earlier work on action teams in dynamic contexts (Lei et al., 2016; Stachowski et al., 2009; Waller et al., 2004). Some original codes did not occur in the dataset and were not included (e.g. "checklist" or "disagree"). In addition, the code "standby" was added to code CLC more specifically to indicate that a team member has heard a message but needs a moment to respond. We further added more specific codes to code more detailed actions towards outside team members and describe specific de-escalation strategies based on our theoretical framework. Hence, we added the codes "verbal use of force", "ask for information", "honesty", and "emphasising humanity" (International Association of Chiefs of Police, 2020; Todak & James, 2018; Todak & White, 2019). Additionally, to describe specific nonverbal actions, codes were added that were specifically based on the use of weapons or functionalities, particularly "using handcuffs" and "opening a door" (Schrom-Feiertag et al., 2021). As such, all codes were grouped into three overarching meta-categories: team interactions, de-escalation, and actions. A "zero behaviour" category was used for actions that were not understandable or irrelevant. The final codebook of 17 mutually exclusive codes, which allows for exhaustive coding of a full range of coordinative actions, is presented in Table 2.

To systematically and reliably code each team member's actions, three students of the University of Twente in the Master's programme Educational Science and Technology independently coded the simulations using the specialised coding software *Observer XT* (Noldus et al., 2000). As transcription of the simulations helps facilitate the coding of behaviours, a transcript was created for each simulation (Waller & Kaplan, 2018). To ensure high inter-rater reliability, more than 15% of each simulation was coded by a rotating student. They had to code the same behaviour as occurring within a 2-second time frame (Hoogeboom et al., 2021). Coding similar behaviour outside the 2-second time frame results in disagreement. In the first round, an inter-rater reliability of 74.0% (Cohen's Kappa = .78; Cohen, 1960) was established, which is considered to be a substantial level of agreement (Landis & Koch, 1977). To achieve a higher level of agreement, students discussed discrepancies and revised the entirely assigned codes based on the final collusion, resulting in a final inter-rater reliability of 90.9% (Cohen's Kappa = .91; Cohen, 1960), which represents an almost perfect level of agreement (Landis & Koch, 1977).

Table 2

Examples of Coded Behaviours

Code Name	Definition	Example
Team interactions		
Command	Specific assignment of responsibility	“You look left; I look right.”
Observe	Noting a fact or occurrence	“There is a door on the right.”
Suggest	Recommendation for action	„Let’s go in one line. “
Opinion	Expression of one’s own opinion	„I think we should escort him outside. “
Inquiry	Request for information, statement, analysis	“What is that?“
Question	Request for confirmation or rejection statement	„Should I open the door for you?“
Acknowledgement	Confirmation (“yes”) or rejection (“no”) statements to indicate that a message has been received or for yes/no replies to questions.	“Yes.”
Answer	Supplying information beyond acknowledgement	“I can see a gun.“
Briefing	Information to team members on what to expect in the next stage. Also used to code the providing of information without request.	„When I open the door, you are directly in line.“
Expression	Comment, emotional remark	“I'm behind you.“
Standby	Used when the speaker has heard the message but needs a moment to process or respond	“Standby”
Actions		
Open a door	Used when a team member opens a door	-
Use handcuffs	Used when a team member handcuffs a suspect	-
De-escalation (towards outside team members)		
Ask for information	Using questions to solicit additional information	„Who are you?“
Emphasising humanity	Social communication with a calm demeanour	„What’s the dogs name?“
Honesty	Explaining the goal, rules or process to an external individual	„We are searching for a suspect.”
Verbal use of force	Using verbal commands	„Get down on your knees!“

Data analysis

At first, the dataset was reviewed and prepared by inserting the stress values obtained from the AAR Software into an excel document. This document comprised four worksheets, each representing a simulation. The first column recorded the time in the format hh:mm:ss, while the second column documented the duration of each simulation in seconds. The remaining columns captured the stress values of each team member, with each cell representing a data point indicating the stress level per second, as recorded by the AAR Software (see Appendix A). As the timer between the AAR Software and Noldus where not equivalent, both timestamps were synchronised to ensure alignment between coded behaviours and timestamps of the stress values. Therefore, the deviation calculated from the start and stop times was utilised to determine the corrected time and duration, which were then included as new columns in the excel document.

To answer the first and second research question, moments of physiological co-occurrence were identified to see how often and when they occur. For this purpose, another column was added, indicating synchronous values between all team members' stress values. Thus, physiological co-occurrence was identified as moments in which synchronous stress values of high or low between team members overlapped. Based on this, calculations within excel per functions for the calculation of frequencies and duration were conducted. Visualisations were created to illustrate each team member's stress level, moments of co-occurrence and contextual factors during the simulations on a timeline. To answer the third research question and test what coordinative actions are displayed during moments of physiological co-occurrence, the coded behaviour through Noldus was downloaded and converted into excel sheets. Based on this, coding frequencies within the previously identified moments of physiological co-occurrence were calculated. A 2-tailed chi-square test in SPSS was conducted to see if frequencies between moments of high co-occurrence and no co-occurrence differed. Since a chi-square test requires high frequencies for validity, the frequencies were aggregated across all teams. For moments of low co-occurrence and within individual simulations, the conditions were not met and a chi-square test could not be performed, so we presented absolute frequencies and team members' proportion of team members' behaviour (Field, 2020; Strick, 2019). To answer the fourth research question, the teams were split into two groups (more versus less effective teams) based on our coded behaviours to explore how physiological co-occurrence can be related to team performance. Due to a low sample size and a non-parametric distribution, a Mann-Whitney U test was conducted to test for differences in the proportion of physiological co-occurrence in both groups.

Results

Frequency and duration of physiological co-occurrence

The frequencies and duration of physiological co-occurrence moments were calculated to answer the first research question of how often these moments happened. An overview of the findings is depicted in Table 3. In total, moments of physiological co-occurrence were observed in all four teams during the simulations. The frequency of these moments ranged from 1 to 7 times per simulation (*M* = 3.50, *SD* = 3.0). 13 (92.8%) of these moments were a high level of physiological co-occurrence, and one moment (7.2%) was a low level of physiological co-occurrence. Overall, the cumulative duration of physiological co-occurrence accounted for a total of 869 seconds (43.3%) across all simulations. Per simulation, the duration ranged from 4 to 541 seconds (*M* = 217.25, *SD* = 259.48), corresponding to a relative amount of 1.7% to 88.5% (*M* = 34.23, *SD* = 41.44). The duration of moments of physiological co-occurrence at the simulation level in *the arrest 1* was about 11 seconds (*M* = 11.00, *SD* = 0). In *the arrest 2*, the duration of moments of physiological co-occurrence ranged from 2 to 211 seconds (*M* = 108.20, *SD* = 88.63). In *the arrest 3*, the duration was about 4 seconds (*M* = 4.00, *SD* = 0). In *the confused person 1*, the duration ranged from 2 to 164 seconds (*M* = 44.71, *SD* = 50.52).

Table 3

Frequencies and Duration of Physiological Co-occurrence

	Frequency		Duration					
	High-level	Low-level	Absolute	Relative	*M*	*SD*	Min	Max
The arrest 1	1	0	11	1.7%	11.00	0	11	11
The arrest 2	5	0	541	88.5%	108.20	88.63	2	211
The arrest 3	0	1	4	2.0%	4.00	0	4	4
The confused person 1	7	0	313	58.6%	44.71	50.52	2	164

Note. This table demonstrates the absolute frequencies of moments of high and low physiological co-occurrence between two team members per simulation. The duration of the moments is given in seconds and the relative amount in percent of the total duration per simulation.

Timing of physiological co-occurrence

To address the second research question and answer when moments of physiological co-occurrence happened, figures are provided that represent each team member's stress level and highlight the timing of physiological co-occurrence moments in each simulation. Additionally, the figures include brief descriptions of the simulation's context to offer further insights into the contextual factors and phases surrounding these moments.

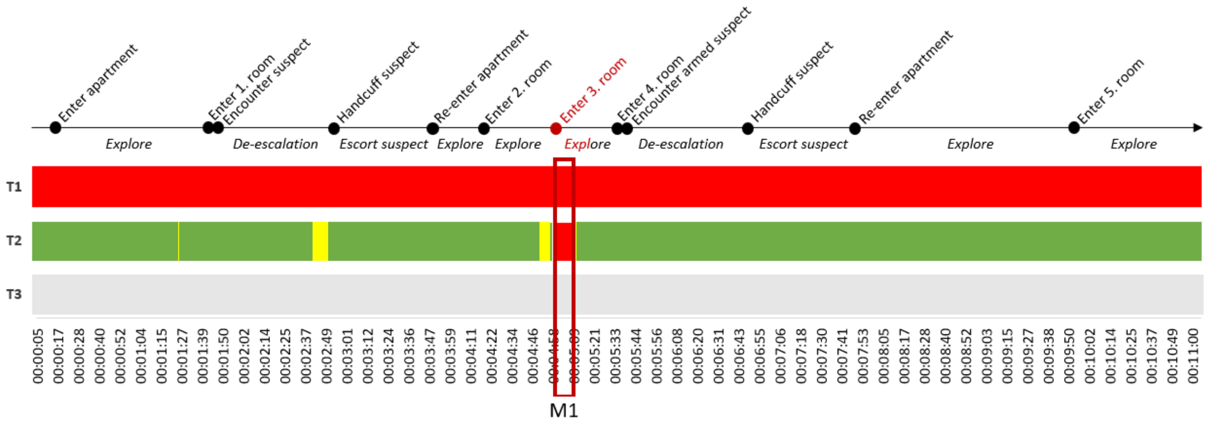
The arrest 1

In *the arrest 1*, the team members T1, T2, and T3 were involved. Due to missing stress values for T3, physiological co-occurrence was only calculated between T1 and T2. Throughout the simulation, T1 consistently exhibited a high stress level, whereas T2 generally remained in a state of low stress. However, at the midpoint of the simulation, T2's stress level suddenly rose to a high level, resulting in a moment of high physiological co-occurrence lasting from minute 05.00 to minute 05.11 (*M1*). An overview is depicted in Figure 2.

One contextual factor that can be identified as the marker of the start of *M1* was *the room entry*. Particularly, in a phase of exploration, T1 and T3 entered a third room, thus separating themselves from T2. Meanwhile, T2 took up a position as a guard in front of the room, which was connected to an increase in his stress level. When T1 and T3 returned to the vicinity of T2, T2's stress level decreased, and *M1* stopped. However, throughout the rest of the simulation, room entries or other contextual elements (e.g. encounter with a suspect) or phases (e.g. exploration, de-escalation, suspect escort) cannot be related to moments of physiological co-occurrence.

Figure 2

Timing and Context of Physiological Co-occurrence in The Arrest 1



Note. One moment of high physiological co-occurrence (M1) is highlighted in red in the timeline.

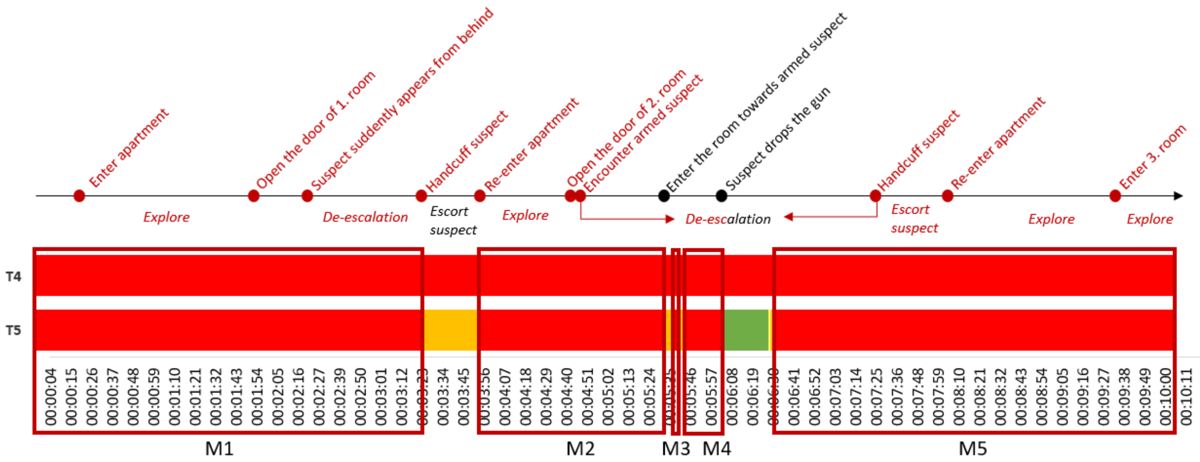
The arrest 2

In *the arrest 2*, the team members T4 and T5 were involved, and physiological co-occurrence between both was calculated. Throughout the simulation, T4 consistently exhibited high stress levels, while T5 fluctuated between continuous moments of high stress and a few moments of moderate and low stress. Overall, five high-level physiological co-occurrence moments occurred. One in the beginning, from minute 00.04 to minute 03.31 (*M1*). Three took place in the middle of the simulation, from minute 04.00 to minute 5.40 (*M2*), from minute 05.45 to minute 05.47 (*M3*) and from minute 05.51 to 06.12 (*M4*). One occurred at the end, from minute 06.40 to 10.11 (*M5*). An overview is depicted in Figure 3.

M1 already started with the *beginning* of the simulation due to the high stress levels of both team members. One contextual element that can be identified as a marker of the start of physiological co-occurrence was the *re-entry into the apartment* (*M2*). The other physiological co-occurrence moments, *M3, M4* and *M5*, started during the second *de-escalation phase* with the suspect, which was characterised by fluctuations in T5's stress level. During moments of physiological co-occurrence, the team *explored* the apartment (*M1, M2, M5*), *de-escalated* with the suspect (*M1, M3, M4, M5*) and *escorted* the suspect outside (*M5*). However, de-escalation and escorting the suspect outside also happened during moments of no physiological co-occurrence. Contextual elements that can be identified as markers of the ending of physiological co-occurrence were *handcuffing* the suspect (*M1*) or when the suspect *dropped the gun* (*M4*).

Figure 3

Timing and Context of Physiological Co-occurrence in The Arrest 2



Note. Moments of high physiological co-occurrence M1-M5 are highlighted in red in the timeline.

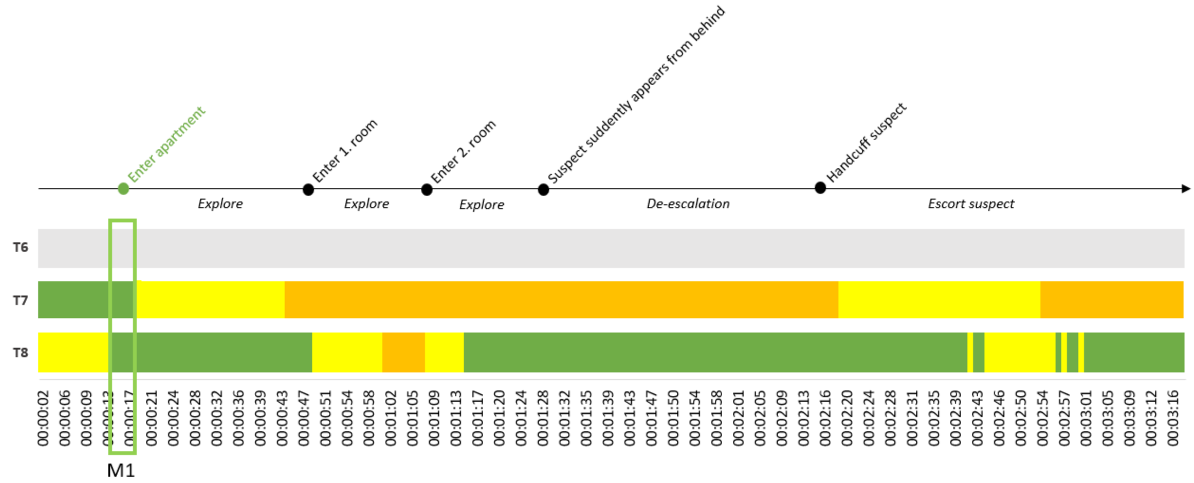
The arrest 3

In *the arrest 3*, the team members T6, T7 and T8 were involved. Due to the absence of stress values for T6, physiological co-occurrence was only calculated between T7 and T8. Both team members exhibited fluctuations in their stress levels. However, T7 initially displayed low stress, gradually decreasing to a medium level, whereas T8 followed the opposite pattern, starting with medium stress and progressively reducing to low levels. During this simulation, a moment of *low* physiological co-occurrence (*M1*) happened at the beginning, lasting from minute 00.14 to minute 00.18. An overview is depicted in Figure 4.

Entering the apartment can be identified as the marker for the start of *M1*. Particularly, *M1* started when the team members *entered the apartment* and stopped when the team members started the exploration. However, during the rest of the simulation, specific contextual elements, such as entering a room or encountering a suspect, were not related to a moment of physiological co-occurrence.

Figure 4

Timing and Context of Physiological Co-occurrence in The Arrest 3



Note. One moment of low physiological co-occurrence (M1) is highlighted in green at the timeline.

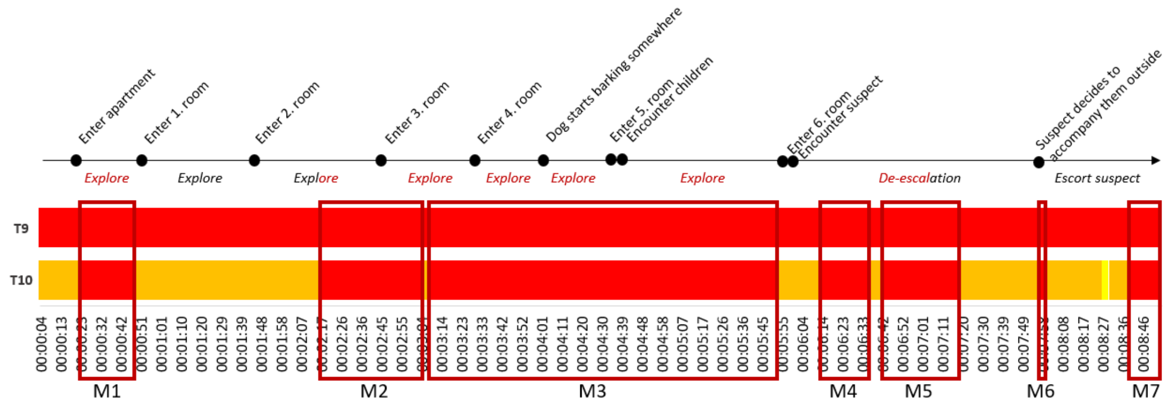
The confused person 1

In *the confused person 1*, team members T9 and T10 were involved, and physiological co-occurrence between both was calculated. Throughout the simulation, T9 consistently exhibited high stress, while T5 fluctuated between levels of high stress and moderate levels of stress. Overall, seven high-level physiological co-occurrence moments took place. One in the beginning, from minute 00.23 to minute 00.47 (*M1*). Five took place in the middle of the simulation, from minute 02.17 to minute 03.04 (*M2*), from minute 03.08 to minute 05.52 (*M3*), from minute 06.14 to minute 06.35 (*M4*), from minute 06.42 to minute 7.20 (*M5*) and from minute 07.57 to 07.59 (*M6*). One occurred at the simulation's end, from minute 08.39 to 8.55 (*M7*). An overview is depicted in Figure 5.

One contextual element that can be identified as a marker of the start of physiological co-occurrence was the *entry into the apartment* (*M1*). *M2* and *M3* started during the exploration phases, *M4* and *M5* during the de-escalation phases and *M6* and *M7* in a phase where the team members escorted the suspect outside. During moments of physiological co-occurrence, the team explored the apartment (*M1, M2, M5*), de-escalated with the suspect (*M4, M5*) and escorted the suspect outside (*M6, M7*). However, exploration, de-escalation and escorting the suspect outside also happened during moments of no physiological co-occurrence. Contextual elements that can be identified as markers of the ending of physiological co-occurrence were *entering a room* (*M1, M3*) or when the *suspect decided to cooperate* (*M6*).

Figure 5

Timing and Context of Physiological Co-occurrence in The Confused Person 1



Note. Moments of high physiological co-occurrence M1-M7 are highlighted in red in the timeline.

Overall, these findings indicate patterns across the simulations. In *the arrest 1*, *arrest 2*, and *confused person 1,* one team member had consistently high stress levels throughout the simulation. As such, moments of physiological co-occurrence took place when the stress level of the other team member increased to a high level. *The arrest 3* was the only simulation where we observed one moment of low physiological co-occurrence and high fluctuations in stress for both team members. However, while T7 experienced increased stress during the simulation, T8 followed a reverse pattern, exhibiting decreased stress.

The timing of physiological co-occurrence varied across the scenarios. Co-occurrence was observed once at the beginning (*the arrest 3*), once in the middle (*the arrest 1*), and twice throughout the entire simulation (*the arrest 2* and the *confused person 1*). Concerning the context in which these moments took place, we noted that separation between team members (*the arrest 1*) and their entry or re-entry into the apartment (*the arrest 2*, *the arrest 3*, *the confused person 1*) were sometimes markers of the start of physiological co-occurrence moments. The end of physiological co-occurrence coincided with moments when the suspect either dropped the gun, was handcuffed (*the arrest 2*) or agreed with the police (*the confused person 1*). However, it is important to note that specific contextual factors did not always mark the start or end of physiological co-occurrence and certain phases, such as exploring the apartment, de-escalating, or escorting a suspect, occurred both during moments of co-occurrence and moments of no co-occurrence. To gain a deeper understanding of these instances, we examined team members' behaviour during these specific moments in the next section.

Behaviours during moments of physiological co-occurrence

To answer the third research question of what behaviours happened during physiological co-occurrence, we compared behaviours observed during co-occurrence and non-co-occurrence moments.

Since low co-occurrence moments were short (4 seconds) and resulted in fewer team behaviours, we will focus on comparing high physiological co-occurrence moments with no co-occurrence moments to ensure the requirements for a 2-tailed chi-square test (Field, 2020). Hence, we compared if behaviours during high co-occurrence differed from those when no co-occurrence occurred. Frequencies were standardised to enable the comparison of frequencies between these moments according to a formula by Endedijk et al. (2018). Table 4 depicts both the standardised frequencies of the behaviours that are displayed by the team members and the proportions during moments of high co-occurrence and moments without physiological co-occurrence.

Overall, the results show that team members displayed significantly more behaviours during moments of physiological co-occurrence, as compared with moments where no physiological co-occurrence was observed ($\chi2(1) = 11.01$, $p < .001$). Regarding the specific behaviours, the results show that team members displayed significantly more *observations* ($\chi2(1) = 13.06$, $p < .001$), *suggestions* ($\chi2(1) = 6.13$, $p < .05$) and *opinions* ($\chi2(1) = 4.00$, $p < .05$) during moments of high physiological co-occurrence than during moments where no physiological co-occurrence was observed. Hence, team members were more likely to provide observations, suggestions and opinions during moments of high co-occurrence with their team members. In addition, *acknowledgement* ($\chi2(1) = 22.02$, $p < .001$) and *answer* ($\chi2(1) = 9.09$, $p < .01$) was significantly higher during moments of high co-occurrence, compared to moments where no co-occurrence was observed. Thus, team members were more likely to provide acknowledgement and answers to their team members during moments of high physiological co-occurrence. Concerning de-escalation techniques, *emphasising humanity* was displayed more often when no physiological co-occurrence was observed, as compared with moments of high physiological co-occurrence ($\chi2(1) = 17.64$, $p < .001$). Hence, during moments of no co-occurrence, team members were more likely to use social communication techniques of *emphasising humanity* towards individuals outside their team. Chi-square calculations were not feasible for the code *standby* due to its zero value. For all other behaviours, the chi-square tests did not demonstrate significant differences between high and no co-occurrence moments.

Table 4

Standardised Frequencies and Chi-Square Results on Aggregated Behaviours of All Simulations

		Moments of high co-occurrence		Moments of no co-occurrence	
Team interactions					
Command		30.16	(5.6%)	35.27	(8.0%)
Observe	***	104.41	(19.2%)	58.20	(13.3%)
Suggest	*	23.20	(4.3%)	8.82	(2.0%)
Opinion	*	11.60	(2.1%)	3.53	(0.8%)
Inquiry		18.56	(3.4%)	10.58	(2.4%)
Question		48.72	(9.0%)	38.80	(8.8%)
Acknowledgement	***	139.21	(25.6%)	70.54	(16.1%)
Answer	**	32.48	(6.0%)	12.35	(2.8%)
Briefing		30.16	(5.6%)	24.69	(5.6%)
Expression		11.60	(2.1%)	19.40	(4.4%)
Standby[a]		0.00	(0.0%)	12.35	(2.8%)
Open a door		18.56	(3.4%)	24.69	(5.6%)
Use handcuffs		4.64	(0.9%)	5.29	(1.2%)
Ask for information		4.64	(0.9%)	3.53	(0.8%)
Emphasising humanity	***	2.32	(0.4%)	22.93	(5.2%)
Honesty		20.88	(3.8%)	31.75	(7.2%)
Verbal use of force		41.76	(7.7%)	56.44	(12.9%)
Total	***	542.93	(100%)	439.14	(100%)

Note. The table shows aggregated and standardised frequencies of team behaviours across all simulations and the percentage of the total number of behaviours in parentheses.

[a] Due to the 0 value, no chi-square calculation is possible

**p* < .05. ***p* < .01. ****p* < .001.

These insights give some general indications of coordinative actions during moments of high physiological co-occurrence and no moments of co-occurrence. Particularly, they show that team members provided *more observations, suggestions, opinions, acknowledgements, and answers in high co-occurrence moments*. In contrast, in *no co-occurrence moments, team members used more often the de-escalation technique of emphasising humanity*. For a deep dive, we will further zoom into behaviours displayed by the team members in the individual simulations.

The arrest 1 – behaviour during high physiological co-occurrence

Table 5 demonstrates the absolute frequencies of team behaviours that occurred during the 11-second lasting moment of physiological co-occurrence and the 654 seconds of no physiological co-occurrence in *the arrest 1* between team members T1 and T2 (see Figure 2). Since co-occurrence accounted for only 1.7% of the total duration, the frequencies could not be standardised due to the highly unequal ratios, which would have caused distortions. Additionally, the frequent zero values did not allow for calculating chi-square tests for comparing the frequencies (Field, 2020).

The results of the absolute frequencies illustrate that, in concordance with Table 4, during the moment of high physiological co-occurrence, team members depicted behaviours of observe, acknowledgement and answer. However, they did not depict suggestion or opinion behaviours but command and inquiry behaviours. When we zoom into the context of this moment *M1*, we can see that T1 and T2 used CLC: T1 observed the room, T3 inquired if he could see somebody, T1 replied back that no one was there, and T3 closed the loop by acknowledging this information and commanding to go back (for a full transcript see Appendix B). During moments of no physiological co-occurrence, T2 emphasised humanity as a form of de-escalation with the suspect when they escorted him outside.

Another interesting aspect is that behaviours only occurred between T1 (40.0%) and T3 (60.0%). That means T2 (0.0%) did not demonstrate any behaviour even though the physiological co-occurrence occurred between him and T1. Overall, the proportions of team members' behaviour seem to differ between high co-occurrence moments and no co-occurrence moments. While T3 was usually rather unobtrusive during the simulation, he acted most during the high co-occurrence moment. The opposite pattern can be seen with T2, who did act in moments were no co-occurrence was observed but not at all during the high co-occurrence moments.

Table 5

Comparison of Behaviours Between High and No Physiological Co-occurrence in The Arrest 1

	High co-occurrence[a]			No co-occurrence[b]		
	T1	**T2**	T3	**T1**	**T2**	T3
Team interactions						
Command	0	0	1	11	4	1
Observe	1	0	0	8	5	3
Suggest	0	0	0	2	1	0
Opinion	0	0	0	0	0	1
Inquiry	0	0	1	2	4	0
Question	0	0	0	6	8	3
Acknowledgement	0	0	1	7	10	4
Answer	1	0	0	2	2	1
Briefing	0	0	0	4	3	3
Expression	0	0	0	1	1	4
Standby	0	0	0	2	2	3
Actions						
Open a door	0	0	0	4	2	0
Use handcuffs	0	0	0	1	1	0
De-escalation						
Ask for information	0	0	0	1	0	0
Honesty	0	0	0	2	3	1
Verbal use of force	0	0	0	6	3	5
Emphasising humanity	0	0	0	0	1	0
Total	2	0	3	59	50	29
Proportion	40.0%	0.0%	60.0%	42.8%	36.2%	21.0%

Note. The table shows absolute frequencies and the proportion of team members' behaviour during one moment of high physiological co-occurrence and no co-occurrence. Physiological measurements are available between T1 and T2 (highlighted in bold).

[a] The duration of high co-occurrence moments 11 seconds

[b] The duration of no co-occurrence moments is 654 seconds

The arrest 2 – behaviour during high physiological co-occurrence

Table 6 demonstrates the absolute frequencies of team behaviours that occurred during 541 seconds of high physiological co-occurrence moments and 70 seconds of no co-occurrence in *the arrest 2* between team members T4 and T5 (see Figure 3). As the moment of high co-occurrence accounted for 88.5% of the total duration, the frequencies were not standardised due to the highly unequal ratios and resulting distortions by standardisation. Due to a zero inflation, it was not possible to calculate chi-square tests to compare the frequencies (Field, 2020).

The results of the absolute frequencies illustrate that, in concordance with Table 4, during the moments of high physiological co-occurrence, team members depicted mostly behaviours of observe and acknowledgement as a form of CLC during phases where they explored the apartment. They further used suggestions and answers to suggest how to proceed with the exploration or answers as a form of replying to what they could see. An excerpt of the transcript from these moments is presented in Appendix B. However, contrary to Table 4, they did not express their opinion. During the moment of no physiological co-occurrence, T4 emphasised humanity the moment they escorted the suspect outside. Another interesting aspect here is that T4 and T5 had a relatively evenly distributed proportion of behaviours, both in the co-occurrence moments and moments where no co-occurrence was observed. In addition, both team members were usually highly stressed and shared a lot of physiological co-occurrence.

Table 6

Comparison of Behaviours Between High and No Physiological Co-occurrence in The Arrest 2

	High co-occurrence[a]		No co-occurrence[b]	
	T4	**T5**	**T4**	**T5**
Team interactions				
Command	4	7	0	0
Observe	17	11	0	1
Suggest	1	4	0	0
Opinion	0	0	0	0
Inquiry	2	4	0	0
Question	6	4	0	0
Acknowledgement	15	17	2	0
Answer	4	2	0	0
Briefing	5	6	0	2
Expression	1	0	0	0
Standby	0	0	0	0
Actions				
Open a door	3	1	0	0
Use handcuffs	2	0	0	0
De-escalation				
Ask for information	0	0	0	0
Honesty	5	0	1	1
Verbal use of force	9	5	3	1
Emphasising humanity	1	0	1	0
Total	75	61	7	5
Proportion	55.1%	44.9%	58.3%	41.7%

Note. The table shows absolute frequencies and the proportion of team members' behaviour during five moments of high physiological co-occurrence and no co-occurrence.

[a] The duration of high co-occurrence moments is 541 seconds

[b] The duration of no co-occurrence moments is 70 seconds

The arrest 3 – behaviour during low physiological co-occurrence

Table 7 demonstrates the absolute frequencies of team behaviours that occurred during the 4-second lasting moment of low physiological co-occurrence and the 194 seconds of no physiological co-occurrence in *the arrest 3* between team members T7 and T8 (see Figure 4). Since co-occurrence accounted for only 2.0% of the total duration, the frequencies were not standardised due to the highly unequal ratios. Due to frequent zero values, it was not possible to calculate chi-square tests to compare the frequencies (Field, 2020).

However, the results of the absolute frequencies indicate that during the moment of low physiological co-occurrence, T8 commanded to enter the apartment, and T7 and T6 acknowledged this (A transcript of this moment is depicted in Appendix B). During the moment of no physiological co-occurrence, team members used mostly verbal use of force as a de-escalation strategy. Another interesting aspect is that during moments of low co-occurrence, all team members were equally involved, whereas, in moments where no co-occurrence was observed, T8 dominated the simulation with a lot of commands, opening the door and de-escalation behaviours. T6 and T7 demonstrated more passive behaviours, such as observations, questions and acknowledgements.

Table 7

Comparison of Behaviours Between Low and No Physiological Co-occurrence in The Arrest 3

	Low co-occurrence[a]			No co-occurrence[b]		
	T6	**T7**	**T8**	T6	**T7**	**T8**
Team interactions						
Command	0	0	1	0	0	4
Observe	0	0	0	0	1	3
Suggest	0	0	0	0	0	0
Opinion	0	0	0	0	0	0
Inquiry	0	0	0	0	0	0
Question	0	0	0	0	1	0
Acknowledgement	1	1	0	1	1	0
Answer	0	0	0	0	0	0
Briefing	0	0	0	0	0	2
Expression	0	0	0	1	0	1
Standby	0	0	0	0	0	0
Actions						
Open a door	0	0	0	0	0	3
Use handcuffs	0	0	0	0	0	1
De-escalation						
Ask for information	0	0	0	0	0	0
Honesty	0	0	0	0	0	4
Verbal use of force	0	0	0	0	2	8
Emphasising humanity	0	0	0	0	0	0
Total	1	1	1	2	5	26
Proportion	33.3%	33.3%	33.3%	6.1%	15.2%	78.8%

Note. The table shows absolute frequencies and the proportion of team members' behaviour during one moment of low physiological co-occurrence and no co-occurrence. Physiological measurements are available between T7 and T8 (highlighted in bold).

[a] The duration of high co-occurrence moments 4 seconds

[b] The duration of no co-occurrence moments is 194 seconds

The confused person 1 – behaviour during high physiological co-occurrence

Table 8 demonstrates the standardised frequencies of team behaviours that occurred during 313 seconds of high physiological co-occurrence moments and 221 seconds of no co-occurrence in *the confused person 1* between team members T9 and T10 (see Figure 5). Since co-occurrence accounted for 58.6% of the total duration, we were able to standardise the frequencies based on a formula by Endedijk et al. (2018) and thus allow a better comparison between behaviours during moments of high co-occurrence and no co-occurrence. However, due to a zero inflation, we were not able to calculate a chi-square test (Field, 2020).

The results of the standardised frequencies illustrate that, in concordance with Table 4, during the moments of high physiological co-occurrence, team members depicted mostly behaviours of observe and acknowledgement as a form of CLC during phases where they explored the apartment. They further used suggestions as a form of proposing how to proceed with the exploration of the apartment, answers as a form of explaining what they can see and opinions to express how they feel about that. However, contrary to Table 4, they also depicted questions to ensure a mutual understanding about how to proceed with exploring the apartment. An excerpt of the transcript from these moments is presented in Appendix B. Another interesting aspect here is that T9 and T10 had a relatively evenly distributed proportion of behaviours, both in the co-occurrence moments and moments where no co-occurrence was observed. In addition, both team members were usually highly aroused and shared a lot of physiological co-occurrence.

Table 8

Comparison of Behaviours Between High and No Physiological Co-occurrence in The Confused Person 1

	High co-occurrence		No co-occurrence	
	T9	**T10**	**T9**	**T10**
Team interactions				
Command	0	0	0	0
Observe	4	12	7	10
Suggest	4	1	3	10
Opinion	2	3	1	0
Inquiry	1	0	0	0
Question	2	9	1	4
Acknowledgement	12	15	10	12
Answer	3	4	1	1
Briefing	2	0	0	0
Expression	2	2	0	3
Standby	0	0	0	0
Actions				
Open a door	1	3	3	4
Use handcuffs	0	0	0	0
De-escalation				
Ask for information	0	2	1	0
Honesty	2	3	4	4
Verbal use of force	3	1	1	4
Emphasising humanity	0	0	12	4
Total	38	55	47	49
Proportion	40.9%	59.1%	49.0%	51.0%

Note. The table shows standardised frequencies and the proportion of team members' behaviour during seven moments of high physiological co-occurrence and no co-occurrence.

Overall, the findings indicate that teams consisting of two team members (*the arrest 2* & *the confused person 1*) shared a lot of physiological co-occurrence and usually had balanced proportions of team behaviours during both moments. In both simulations, behaviours of observe, suggest, opinion, acknowledgement and answer were mostly depicted to communicate about how to proceed with exploration. In contrast, in teams with three team members (*the arrest 1* & *the arrest 3*), team members shared only a brief moment of physiological co-occurrence and had uneven proportions of team behaviours during co-occurrence moments and moments where no co-occurrence was observed. While in *the arrest 1* one moment of high co-occurrence took place between team members who did not interact with each other, in *the arrest 3*, the moment of low co-occurrence took place when all three team members were equally involved. For a deep dive and further insights into each specific moment of physiological co-occurrence, we provide an excerpt of the transcript for each simulation in Appendix B.

Post-hoc analysis: relation between co-occurrence and team performance

To answer the fourth research question, we used the *anticipation ratio* (Entin & Serfaty, 1999) to identify effective versus less effective teams and explore if co-occurrence is related to team performance. The anticipation ratio is an operationalisation of team effectiveness derived from our coding, which has been applied in similar contexts (Stachowski et al., 2009). This ratio represents the proportion of coded information transfers (*observation* and *briefing*) to coded information requests (*inquiry* and *question*). Higher ratios indicate that team members anticipate their teammates' information needs and "push" them information before their request, signifying higher implicit coordination and shared situational awareness. In contrast, lower ratios represent a lack of anticipation, thereby resulting in the need to "pull" information from one another (Stachowski et al., 2009). As the total duration of the simulation highly influences the team's frequencies, the coded team behaviours of *observation, briefing, inquiry* and *question* were standardised according to the shortest video using a formula by Endedijk et al. (2018).

Table 9 gives an overview of these frequencies and the calculated anticipation ratio per simulation. Overall, among all teams, observe and briefing behaviours ranged from 3.87 to 13.61 (M = 8.65, SD = 4.49) and were significantly higher than inquiry and question behaviours ranging from 1.0 to 5.93 (M = 3.62, SD = 2.32) $t(6) = 1.98, p < .05$. That means the teams transferred more information than requested. Furthermore, we classified the four teams into two separate groups based on the median of the anticipation ratio, with more effective teams (anticipation ratio > $\tilde{x}$) versus less effective teams (anticipation ratio < $\tilde{x}$). Thus, we classified *the arrest 3* with a score of 6.0 > 3.0 (M = 6.00, SD = 0.00) as more effective, while the other three teams can be classified with scores from 1.63 to 2.63 < 3.0 as less effective (M = 2.05, SD = 0.42). The results are presented in Table 10. Due to a low sample size and a non-parametric distribution, a Mann-Whitney U test was performed to evaluate whether the proportion of physiological co-occurrence differed in both groups. However, there is need to consider that we compared the mean of one team with the mean of three teams. The results indicated that there was no significant difference between the proportion of physiological co-occurrence of more effective teams and the proportion of physiological co-occurrence of less effective teams $U = 1.0$ $z = -.45$, $p = .655$.

Table 9

Standardised Frequencies, Anticipation Ratio and Duration of Physiological Co-occurrence Across All Teams

		Team Behaviours			Physiological co-occurrence	
Team	Group	O&B	I&Q	Anticipation Ratio	Total duration	Relative proportion
The arrest 3	More effective	6.00	1.00	6.00	4	2.0%
The arrest 1	Less effective	3.87	2.38	1.63	11	1.7%
The arrest 2	Less effective	13.61	5.18	2.63	541	88.5%
The confused person 1	Less effective	11.12	5.93	1.88	313	58.6%

Note. The table gives an overview of the standardised frequencies of observing and briefing (O&B) behaviours and inquiry and question (I&Q) behaviours per simulation, and the calculated anticipation ratio. The duration of physiological co-occurrence is in seconds and the relative proportion per team.

Table 10

Comparison of More Effective Versus Less Effective Teams in Terms of Duration of Physiological Co-occurrence

	Anticipation ratio		Physiological co-occurrence	
	M	*SD*	*M*	*SD*
More effective teams mean rank	6.00	0.00	2.00	0.00
Less effective teams mean rank	2.05	0.42	49.60	36.00

Note. The table gives an overview of the anticipation ratio and proportion of physiological co-occurrence in more effective teams ($n = 1$) and less effective teams ($n = 3$).

Discussion

Discussion of findings

Understanding team behaviours in police teams during stress is crucial because these teams need to perform in complex, unforgiving environments which require optimal task performance to ensure the personal safety of individuals (Giessing, 2021). It is critical to understand how stress emerges among team members and their coordinative behaviours in high-stress scenarios, as their responses to stress can be shared, intensified, and ultimately influence their overall team performance (Denk et al., 2021; Sassenus et al., 2022). This study combined measurements of physiological stress based on HRV with minute video coding to analyse the emergence of physiological co-occurrence among four police teams by identifying contextual elements and comparing their specific coordinative actions during moments of high physiological co-occurrence and moments where no physiological co-occurrence was observed. It is important to note that we were only able to measure co-occurrence between two team members per simulation due to missing values, although teams sometimes collaborated with three team members. Thus, we can only speak of co-occurrence in the team in the simulation, *the arrest 2* and *the confused person 1,* as these simulations consist of two team members. In the simulation the *arrest 1* and *the arrest 3*, we analysed the coordinative actions of all team members, even though we measured the dyadic physiological co-occurrence. The main findings are discussed in the following.

Frequency and duration of physiological co-occurrence among police teams

First, we aimed to answer how often moments of physiological co-occurrence took place. Previous research has provided evidence that when individuals are in close proximity so that they can see each other, their physiological signals tend to synchronise (Palumbo et al., 2016). We were able to identify moments of physiological co-occurrence among all four simulations. One of these thirteen physiological co-occurrence moments appeared as low-level physiological co-occurrence, with all others being high-level physiological co-occurrence moments. With these findings, we demonstrated that physiological co-occurrence is a relevant construct in the context of police teams and that stress of police team members can be shared. Interestingly, the frequency and duration of physiological co-occurrence varied considerably across the simulations. In some teams, moments of physiological co-occurrence happened only once and made up 1.7% - 2.0% of the simulation's duration. In contrast, in the other teams, more than half of the simulation consisted of physiological co-occurrence moments, which occurred five to seven times. This is in line with previous studies that found that the amount of co-occurrence varied between teams during collaboration (Haataja et al., 2018) and indicates that physiological co-occurrence does not occur by chance when individuals are in the same situation (Behrens et al., 2020). Particularly, the emergence of physiological co-occurrence appears to vary among teams. The theory of cognitive appraisal offers potential explanations, suggesting that physiological co-occurrence stems from the sharedness of stress appraisals derived from the environment (S. Liu & Liu, 2018; Sassenus et al., 2022). Teams who share a lot of physiological co-occurrence might tend to experience simultaneous appraisals of contextual factors, whereas teams with fewer moments of physiological co-occurrence might have diverse perceptions of the situation and thus differ in their stress responses (S. Liu & Liu, 2018). These findings contribute to the recognition of contextual influences to understand the emergence of co-occurrence and collaboration processes. In this regard, we address important contextual factors with our second research question.

The timing of physiological co-occurrence among police teams

Second, we examined when moments of co-occurrence between team members happened. As recommended by Langley (1999), we created visualisations as they are particularly valuable for analysing process data to show precedence, parallel processes and the passage of time. First, our visualisations revealed some patterns in the physiological stress of team members. Interestingly, in three of four simulations, one team member had consistently high-stress levels throughout the simulation. There was only one simulation where fluctuations in both team members' physiological stress were visible, with a reverse pattern in the increase and decrease of stress throughout the simulation. Following previous studies, high fluctuation in stress allows for faster adaption and greater behavioural flexibility in challenging situations, while consistent stress indicates a reduced ability to respond effectively (Gancitano et al., 2021; Giessing, 2021). It is conceivable that a higher stress level is determined by personal characteristics, such as cardiovascular fitness or resilience to stress, years of experience or the role of the team members (Gancitano et al., 2021). However, research also suggests that when the brain constantly processes information in the hypothalamus region, it sends signals to stimulate body functions (Gancitano et al., 2021). We did see that in moments where team members were confronted with potential dangers, such as being separated from the group and standing guard (*the arrest 1*) or de-escalate with a suspect (*the arrest 2* & *the confused person 1*). Further, we observed the separation of team members or the entry or re-entry into the apartment as markers of the start of physiological co-occurrence moments. Markers for the end were when the suspect dropped the gun, was handcuffed, or agreed with the police. These findings align with the theory of cognitive appraisal and adds to our understanding of the emergence of physiological co-occurrence. Specifically, it suggests that high physiological co-occurrence can be related to the sharedness of stress appraisal among team members, particularly in response to a perceived threat-stimuli (LeDoux & Pine, 2016; S. Liu & Liu, 2018). That means when both team members perceive a threat, their physiological stress increases, resulting in high physiological co-occurrence, with the physiological stress decreasing when the perceived danger decreases so that the moments of high physiological co-occurrence stop. However, we also found that events such as handcuffing a suspect or escorting a suspect, that is, the threat decreases, also occurred during moments of high physiological co-occurrence. Further, events such as the encounter with a suspect were not always related to high physiological co-occurrence.

Even though these findings contradict the theory of cognitive appraisal for explaining the emergence of physiological co-occurrence fully, they are in line with Sassenus et al. (2022), who found that team members where not always simultaneously triggered by the same stressor. This suggests that the emergence of co-occurrence cannot always be explained by the simultaneous perception of a threat and stress responses of two individuals. It is possible that physiological co-occurrence is sustained between two partners as long as they coordinate their actions, which would contribute to the idea that high physiological co-occurrence emerges through transferred stress responses (Barsade, 2002). In this regard, previous studies suggest that physiological co-occurrence results more from social interaction rather than intrapersonal processes (Behrens et al., 2020). This emphasises the significance of examining the specific behaviours exhibited between team members, which is addressed with our third research question.

Team behaviours in co-occurrence versus no co-occurrence moments

Third, we analysed team members' behaviours by comparing moments of co-occurrence with moments where no physiological co-occurrence was observed to better understand how team members coordinate their actions and how this can be related to the emergence of physiological co-occurrence. The investigation revealed that teams depicted a wider variety of coordination behaviours in high co-occurrence than in moments without co-occurrence. This finding goes hand in hand with research demonstrating that co-occurrence elevates during the actual interaction rather than being an artefact of being in the same situation, that is, collaborating in the same VR simulation (Behrens et al., 2020). That means physiological co-occurrence emerges particularly through team members' coordinative actions, which aligns with the theory of emotion contagion, meaning that team members transfer their stress responses through their interactions (Barsade, 2002; Herrando & Constantinides, 2021). Further, our findings revealed that team members depict particularly more observations, suggestions, opinions, acknowledgements, and answers in high co-occurrence moments. This indicates that during these moments, team members adjust their actions by observing the situation and the apartment, suggesting ways to proceed with its exploration, stating their opinion about the course of action and providing acknowledgements and answers to confirm their approach. These coordinative actions are in line with the set of behaviours of CLC, particularly in order to monitor their progress, back-up each other, and adapt quickly as the situation unfolds. Interestingly, team members revealed less de-escalation behaviours, even though we only found a significant difference in emphasising humanity. That means team interactions between team members seem to increase in high co-occurrence moments while emphasising humanity, as a form of de-escalating a situation with a suspect, is more displayed in moments where no co-occurrence was observed. This confirms Schneider et al. (2020), who found that physiological co-occurrence increases when individuals work together and decrease when they work independently. In our study, physiological co-occurrence increases when team members interact with each other and decrease when they interact with somebody outside their team. One possible explanation for this is that when team members shift their attention outside of their team, their physiological values become segregated. This finding aligns with the theory of emotion contagion and research suggesting that periods of dissimilarity between individuals occur when they ignore the state of or do not correspond with a partner (Barsade, 2002; Marci et al., 2007; Palumbo et al., 2016). Consequently, this segregation may assist police team members in effectively communicating with a suspect and employing the de-escalation technique of emphasising humanity, enabling them to engage with the individual on a personal level. As previous studies indicate that empathy correlates with high physiological co-occurrence (Marci et al., 2007), it would be valuable to investigate whether police officers separate from their team members while synchronising their physiological responses with the suspect when utilising the technique of emphasising humanity.

To gain additional insights, we proceeded to examine the behaviours depicted by the team members in the individual simulations and found that teams consisting of two team members shared a lot of physiological co-occurrence and had balanced proportions of team behaviours during both moments, while teams consisting of three team members shared less physiological co-occurrence and had uneven proportions of team behaviours during moments of co-occurrence and no co-occurrence moments. One possible explanation could be that in teams of three, members are more able to process a substantial amount of information during complex situations, resulting in enhanced situational awareness as the situation unfolds (Ouverson et al., 2021). This awareness, in turn, leads to reduced shared stress. This finding contributes to our comprehension of cognitive appraisal theory, specifically emphasising that when team members feel they have the resources to process a lot of information, they tend to appraise contextual factors as less stressful (S. Liu & Liu, 2018; Sassenus et al., 2022). Consequently, this may lead to moments of low co-occurrence, as in *the arrest 3*, or even no moments of physiological co-occurrence, as team members may appraise stressors differently. An alternative explanation regarding emotion contagion could be that teams of two members have more opportunities to interact so that they are mutually triggered by their stress responses, leading to more physiological co-occurrence. In teams of three, interactions are naturally more unbalanced, and thus there is less co-occurrence. These findings confirm the idea that the more team members communicate and interact with each other, the more their physiological values tend to synchronise (Behrens et al., 2020; Y. Liu et al., 2021). Therefore, it might be that the coordination of actions in teams with more than two team members is naturally more imbalanced so that not only their behaviours but also their physiological signals run asynchronously. Another reason for these unbalanced interactions could be a free-rider effect, which is more likely to occur when the team sizes increase (Albanese & van Fleet, 1985). Accordingly, previous research about physiological co-occurrence during collaboration suggests that a free rider effect might be indicated through less physiological co-occurrence between team members (Schneider et al., 2020). That could mean that a poorer quality of collaboration can be detected through levels of physiological co-occurrence, which goes hand in hand with previous research that suggests that physiological co-occurrence is related to high collaboration quality (Y. Liu et al., 2021; Mayo et al., 2021). However, we would like to point out again that we must view this assumption with caution, as we could only calculate the co-occurrence of two team members in teams of three due to missing stress values. In addition, we lack information on the demographic data of team members to interpret results. It is also conceivable that one person dominating the simulation (*the arrest 3*) is not due to a free-rider effect of the others but due to his role as a commander or leader or based on the instructions given concerning the task of the VR simulation. In this regard, it would be interesting to study whether the role of a team member influences the emergence of physiological co-occurrence.

Relation between team performance and physiological co-occurrence

As a final step, we examined whether physiological co-occurrence can be related to team effectiveness and found that all teams transferred more information than requested. This indicates that the teams used effective communication patterns, specifically sharing information before it was needed (Schraagen & Rasker, 2001). Based on the calculated anticipation ratio, we separated the teams into two groups: more effective versus less effective teams, but found a right-skewed distribution and classified only *the arrest 3* as more effective, which is the only simulation where we observed fluctuations in the physiological stress of both team members. Thus, our findings are in line with previous research demonstrating that high fluctuations in stress are related to high team performance (Gancitano et al., 2021). Besides, *the arrest 3* stood out as the only simulation where we observed one moment of low co-occurrence. This implies that shared stress among team members could reduce their performance, which aligns with existing research that posits that stress hinders their capacity to process information, recognise critical elements and adapt effectively (Dietz et al., 2010). In addition, *the arrest 3* is the simulation where we found that one team member dominated the simulation, and the teams depicted mostly commands, observations and acknowledgements while codes such as suggest, opinion or inquiry were not displayed. This is in line with research that suggests that more effective teams engage in fewer and less complex interactions (Waller & Kaplan, 2018) and that in more effective teams, one member is more dominant (Endedijk et al., 2018). This indicates that police teams need clear decisions and effective coordination. However, we must interpret this cautiously due to the small sample size.

Moreover, we examined whether more or less effective teams demonstrated more physiological co-occurrence but did not find a significant difference between both groups. Thus, we could not replicate previous research findings that physiological co-occurrence is associated with team performance (Mayo et al., 2021). Here, however, current research seems to be generally non-transparent. While overall, a positive relationship is found (Mayo et al., 2021), other studies found a negative relationship with performance-relevant outcomes (Henning et al., 2009; Strang et al., 2014). Further studies with larger samples looking at different contextual variables are needed to substantiate possible explanations. However, this again highlights the complexity of collaboration and the need for studies that can address the complexity using multimodal measures.

Limitations

Our study has several limitations that should be considered when interpreting the results. One important limitation is the limited number of teams, which affects our findings' statistical power and generalisability. A larger sample size would have facilitated more statistical options, such as a t-test, to investigate potential relationships between the frequency and duration of physiological co-occurrence and the team size. Although we observed a pattern where teams of two shared more physiological co-occurrence, our small sample size prevented conducting a t-test to generalise this finding (Field, 2020). Additionally, the low frequencies of team behaviours during moments of low co-occurrence did not allow for conducting a chi-square test to investigate differences in team coordination during such moments (Field, 2020). Third, a t-test with a larger sample size could allow for a more valid grouping into more versus less effective teams and investigate whether the duration of physiological co-occurrence differs significantly in both groups. This could add to our understanding of whether physiological co-occurrence can be related to team performance. Although our sample size is small, it is worth noting that it facilitated an in-depth analysis and that further multimodal studies investigating physiological co-occurrence in the context of collaborative teams have worked with similar team sizes (Haataja et al., 2018). While acknowledging that these findings may not be fully generalisable due to the sample size, they nevertheless serve as a valuable foundation for further research to compare and verify our results in a wider range of teams.

Besides the small sample size, we were only able to calculate the co-occurrence between two members in teams of three due to missing values. Consequently, caution is needed when interpreting the results, especially regarding the comparison between moments of co-occurrence and moments where no co-occurrence was observed. As previous research on collaborative teams calculated physiological co-occurrence between dyads within a group (Haataja et al., 2018; Palumbo et al., 2016), we made the deliberate decision to incorporate teams with at least stress values from two members into our exploratory study. This allowed us to calculate physiological co-occurrence between these two members and gain intriguing insights into the coordination of actions and patterns within physiological processes. As a result, we identified notable differences in the proportion of team behaviours and duration of physiological co-occurrence in teams of two compared to teams of three.

Furthermore, we lack information about the team members, such as their age, years of experience, and roles, which could have provided valuable insights for interpreting their behaviours or stress levels. Even though previous studies have suggested that characteristics like years of experience do not affect physiological stress in police officers (Baldwin et al., 2019), the role of a team member, such as a leader or commander, would explain more about why certain behaviours were depicted or why the proportions of team behaviours were more unbalanced. In this regard, there is also a need to point to our striking gender distribution. Research found that HRV measures vary across gender

(Williams et al., 2022) and that male and female officers experience stressors differently and also differ in their coping behaviour in response to stress (Bonner & Brimhall, 2022).

Another limitation of our study is the stress algorithm used to calculate physiological co-occurrence. The advantage is that this approach helps to identify moments of high, intermediate and low stress and overlaps in the stress values of team members. A similar stress algorithm and approach have also been applied in previous research (Sassenus et al., 2022). However, this resulted in a variable scaled ordinally, leading to the loss of informative nuances. To enhance the informativeness of the results, alternative methods could have been employed when original HRV data was available. These methods consider individual fluctuations and measure physiological co-occurrence by examining the correspondence of signals at each time point. Prominent approaches include the physiological concordance index (Marci et al., 2007), directional agreement (Dich et al., 2018) or dynamic time warping (Snijdewint & Scheepers, 2022).

Regarding the operationalisation of team performance, the anticipation ratio has its limitations as a measure, and it primarily reflects team process rather than team effectiveness. To enhance its appropriateness, it would have been beneficial to validate it with expert performance ratings and examine its correlation with the anticipation ratio (Stachowski et al., 2009). In addition, the conducted median split as a method for determining more effective versus less effective teams can be criticised as they reduce statistical power (McClelland et al., 2015). However, because of our right-skewed distribution, we decided to use this method as a general indication of team performance.

Moreover, it is also essential to consider the potential disadvantages of using VR. We encountered instances where one team member experienced motion sickness and had to end the simulation beforehand, while another team member faced technical issues with the microphone during the VR session (see Appendix B). These factors may have negatively influenced team members' engagement within the simulation (Kleygrewe et al., 2023). Additionally, team members were confronted with different contextual elements in the two scenarios, which challenges the comparison of *the arrest* simulations with *the confused person* simulations. In *the arrest* scenarios, there was one suspect without a weapon and one with a weapon. In *the confused person,* a dog was used as a stress cue, and the suspect was not armed but suicidal. Thus, the two scenarios differ in their task demands. To facilitate meaningful comparisons, conducting identical simulations with a larger sample size on a one-to-one basis would be beneficial (Giessing, 2021).

Theoretical Implications

The present study adds value to current research on different levels. First, while most multimodal studies in the context of collaboration focus on one modality (Schneider et al., 2021), the present study combined two modalities: physiological stress and team behaviours. Thus, this study demonstrates advantages from which future research can benefit. First, automatic data collection through wearable sensors is an affordable and time-saving option, and the objective approach offered more accurate and less biased assessments compared to self-reports of stress (Sjøvold et al., 2022). Thereby, we were able to capture the temporal nature of team behaviour during stressful circumstances, which allowed to better understand how these processes change depending on the time and context they occur (Lehmann-Willenbrock, 2017). Specifically, we effectively tracked the emergence of physiological co-occurrence and how team members behave during these moments, thus extending research on cognitive appraisal and emotion contagion with objective, large, and fine-grained information about teams' collaboration processes as they unfold over time (Barsade, 2002; Herrando & Constantinides, 2021). This in-depth analysis is an important step into understanding how physiological co-occurrence is formed by a large variety of inter- and intrapersonal processes to fully understand the phenomenon of physiological co-occurrence in teams (Sassenus et al., 2022).

Second, our findings implicate that the measurement of physiological co-occurrence alone cannot tell much about collaboration processes in action teams. By zooming into the specific context in which moments of physiological co-occurrence occur and identifying contextual factors surrounding these moments, we linked the theory of cognitive appraisal to physiological co-occurrence, which helped us better comprehend how physiological co-occurrence can be attributed to the simultaneous appraisal of stress factors (S. Liu & Liu, 2018). Our findings indicate that not all contextual factors are consistently related to co-occurrence, so that cognitive appraisal theory alone cannot fully explain the emergence of physiological co-occurrence. By exploring the theory of emotion contagion, we revealed that stress is transmitted through coordinated team actions (Barsade, 2002). As a result, the findings show that high physiological co-occurrence involves more than shared stress appraisal; team members mutually influence and transfer stress responses to each other as they interact. This is an important contribution to understanding physiological co-occurrence that emerges and sustains during the collaboration processes of action teams (Palumbo et al., 2016).

Third, this study is the first that examines the construct of physiological co-occurrence between police officers using VR. We have uncovered team members depicted a wider variety of coordinative actions during moments of high physiological co-occurrence, indicating that shared stress influences team members' behaviour. Additionally, the findings suggest that team members transfer their physiological responses to their team members, underscoring the importance of considering police team members' stress levels not only on the individual level but also at the team level. Consequently, we have expanded the concept of physiological co-occurrence to encompass teams operating in high-pressure scenarios. By using VR as a research tool, we were able to see how these teams respond emotionally and behaviourally under stressful circumstances and thus contribute to the growing interest in the use of VR for research purposes (Giessing, 2021). To the best of our knowledge, this study is the first that zooms into specific team behaviours during moments of physiological co-occurrence using VR (Mayo et al., 2021). Thereby, we imply that VR can be used as an appropriate research tool, enabling us to come closer to the reality of team dynamics and stress responses.

Practical Implications

VR training is becoming increasingly popular for police teams, but this study revealed some aspects of the design and implementation, particularly as this study has taken the first step in applying fine-grained measurements of team behaviours during VR collaboration.

First, VR training for police teams provides engaging and mistake-tolerant opportunities to train certain skills and coordinate under stressful conditions without the risk of human injury (Zechner et al., 2023). Thus, police officers learn to coordinate their actions effectively under stress before they encounter them in real life. We found that there are indeed some stress cues that are highly relevant for individual officers, such as a dog barking for individuals who feel anxious with dogs and the need to adapt team behaviours (see Appendix B). This implies that it might be worth adapting simulations based on individual stressors to confront police officers with their training needs.

Second, the AAR Software is a tool that tracks different aspects, such as sighting lines, walking lines, visual field or individual stress levels and is valuable for debriefing sessions where police officers can reflect on their performance (Giessing, 2021). Our study's findings highlight the importance of considering not only individual stress levels but also shared stress levels. In this regard, we propose widening the perspective of police stress to team stress by incorporating shared stress levels into the AAR Software. This would draw attention to the necessity of addressing team stress and could be utilised for feedback and training on effective coordinative actions and team-level coping strategies, ultimately enhancing team performance (Dietz et al., 2010; Sassenus et al., 2022). To establish a link between team stress and coordinative actions, an additional essential contribution would be to incorporate information about team members' behaviour into the Software. For instance, it might be enriched with the option to differentiate between team members' microphones and include their proportion of speaking time, measured by the activation rate of their microphone, to see who dominated the situation to review and discuss that in debriefing sessions. Probably one day, technological developments might even allow for more sophisticated feedback, such as specific team behaviours depicted through automatic measurements based on automatic voice recognition.

Another implication of this study is that police teams should have a certain level of experience to engage in VR training meaningfully. It occurred that some team members struggled with opening the door or using handcuffs. Thus, they could not fully exploit the potential of using VR as a training tool, which might impair their learning effect or their stress responses (Kleygrewe et al., 2023). As follows, it is advisable to instruct individuals with a tutorial in advance to give them enough time to become familiar with these environments.

Future research

The results of our exploratory study can serve as a stepping stone for future research. First, as also recommended by previous research, we recommend future studies to adapt fine-grained measurements of team behaviours using minute video coding (Hoogeboom et al., 2021). In the context of police teams, the coding scheme used in this study can be applied to capture team members' coordinative actions. This study found a difference in the proportion of team behaviours between team members. Hence, in line with previous studies that distinguish between measuring not only the content but also the structure of team interactions (Endedijk et al., 2018), we recommend analysing and comparing not only specific team behaviours but also the proportions that team members display to interpret the interactions and their context. In this regard, it would be further interesting to combine these measurements with interviews of team members to understand more about how they experienced these situations. Even though research indicates that physiological co-occurrence is an unconscious process (Barsade, 2002; Schneider et al., 2020), understanding why team members displayed certain behaviours or took charge in specific moments and how their perceptions might have been influenced their team members' perceptions of responses, would add valuable insights to our findings.

Second, our study explored how physiological co-occurrence emerges in light of the cognitive appraisal theory and emotion contagion (Barsade, 2002; S. Liu & Liu, 2018). However, we still do not yet know the specific triggers of physiological co-occurrence between team members. It would be beneficial to understand which factors contribute to the emergence of physiological co-occurrence and to deliberately include them in studies as input variables. This would allow understanding of how they influence team processes and team outcomes (Kazi et al., 2021). In addition, studying correlations between certain variables, such as demographics or contextual factors, could explain why and under which conditions physiological co-occurrence happens more or less between team members. Our results suggest that co-occurrence happens more often in teams of two team members instead of three. Future research could investigate whether this is a coincidence or can be confirmed with larger samples. It would also be interesting to know whether team size is a causal explanation or whether it can be explained by the interactions of teams, such as the fact that smaller teams have more equal shares and proportions of speech.

Third, our results have not shown that physiological co-occurrence is related to team performance. Measuring the anticipation ratio gives a first indication of which team can be classified as more effective, but again it is advisable to look at the context. We, therefore, recommend that future research additionally measures team performance through an expert rating for each team to ensure the appropriateness of the anticipation ratio. As the anticipation ratio is considered more a measure of team processes than team effectiveness, combining it with an expert rating has also been effectively performed in previous studies (Stachowski et al., 2009).

Fourth, in future studies, it is worth exploring the incorporation of multiple physiological stress indicators, such as HRV, EDA and cortisol, to enhance the comprehensiveness of assessing the stress levels of team members. Examining various stress indicators simultaneously is a well-established method in stress research, as distinct physiological markers offer unique insights into the body's response to stress (Kazi et al., 2021). Even though HRV was found to be an appropriate indicator of police officers' stress responses (Kleygrewe et al., 2023), researchers found different results depending on the stress indicator used for measuring physiological co-occurrence (Behrens et al., 2020). For that reason, a few studies have combined different stress indicators for measuring physiological co-occurrence, such as cortisol, alpha-amylase and subjective stress (Denk et al., 2021). It is yet, still not clear which is the best physiological measure for calculating physiological co-occurrence (Mayo et al., 2021).

Conclusion

Effective coordination of actions is vital in the high-stress circumstances of police work. VR is not only promising and more and more used as a training method for police teams, but it can also be used in combination with wearable sensors as a multimodal research tool to investigate complex and multifaceted team processes. This study is an example of how data from wearable sensors and minute video coding can be used to enhance our understanding of how teams coordinate their actions under highly stressful conditions. The explorative nature of this research revealed initial insights and patterns about team members' shared physiological stress and accompanying team behaviours, particularly, that physiological co-occurrence can be related to the transmission of cognitive appraisals through coordinative actions. Overall, this study makes a meaningful contribution to advancing our comprehension of the emergence and potential effects of physiological co-occurrence in a highly stressful team context. It underscores the potential of studying physiological co-occurrence for explaining team behaviour and processes. Consequently, this research holds significance for both academic research and practice, providing in-depth insights into the complexity of collaboration processes under stress.

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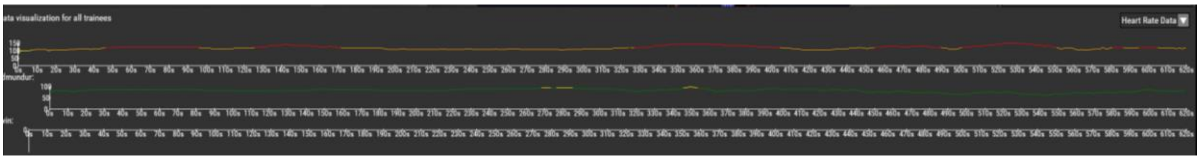
Appendix

Appendix A: Screenshots of the AAR-Software

Figure A1

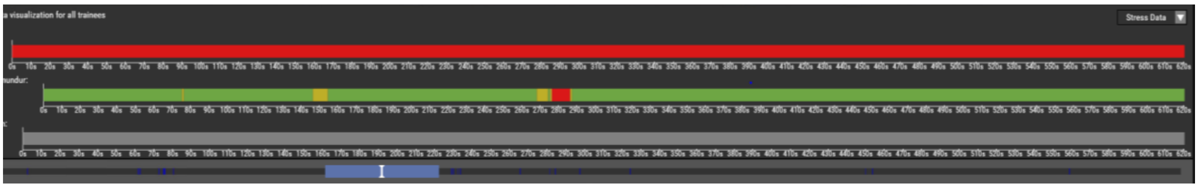
Example of the HRV Data



Note. This screenshot illustrates the HRV data of three team members in one simulation.

Figure A2

Example of Stress Values



Note. This screenshot illustrates the stress values of three team members in one simulation.

Figure A3

Example of one Simulation

Appendix B: Transcripts of the simulations during moments of physiological co-occurrence

The arrest 1

Moment 1 – 05.00-05.11	
T1	"It's a kitchen."
T3	"A kitchen. Is there anyone?"
T1	"No one is here."
T3	"No one is there. Ok. We go outside."

The arrest 2

Moment 1 – 00.04-03.31	
T4	"There is a floor; on the right side, there is another floor. In this direction, there is a bike, and the other floor is going to the right."
T5	"Ok."
T4	"Should I go first?"
T5	"Yes, it's ok; I will follow you."
…	…
Suspect	"Hey! What's wrong? That's my house."
T4	"Raise your hands, freeze."
Suspect	"Why? What are you doing here?"
T4	"We are searching for a suspect."
Moment 2 – 04.00-05.40	
T4	"Yeah, go inside again."
T5	"You first?"
T4	"Yes."
…	…
T4	"Be careful; when I open the door, you are directly in the line."
T5	"Yeah."
Suspect2	"Get out here!"
T5	"Sir, show your hands!"
Moment 3 – 05.45-05.47	
T5	"This is the police; drop the gun!"
Moment 4 – 05.51-06.12	
T4	"Watch out, a gun…"
T5	"He is going... he is at the back. He is at your side."
T4	"Drop your gun and get down on your knees."
Suspect2	"I don't have a gun."
Moment 5 – 06.40-11.10	
T5	"Turn around."
T4	"You are arrested. I will cuff you, and then we will bring you out."
T4	"Can you see where he dropped the gun?"
…	…
T5	"I will check this room."
T4	"There is a door left on your right side."
…	…

The arrest 3

Moment 1 – 0.014-00.18	
T8	"Ok, we go in line, you behind me, and I will open the door."
T7	"Ok."
T6	"Yeah."

The confused person 1

Moment 1 – 00.23-00.47	
T10	"Oke. Eerst rechts."
T9	"Oh, ik hoor jou niet. "
…	…
T10	"Ik krijg de deur niet open."
T9	"Zal ik dan maar eens proberen?"
T10	"Wil jij eens proberen?"
Moment 2 – 02.17-03.04	
T10	"Hier staat ook nog een kastje."
T9	"Mhm, mhm."
…	…
T9	"Slaapkamer met…"
T10	"…wat is dat, dat daar ligt?"
T9	"Granaten."
T10	"Granaten?"
T9	"Drie granaten."
Moment 3 – 03.08-05.52.	
T10	"En een teddybeer"
T9	"Oké. Een granaat en een teddybeer."
T10	"En dat is ehhh… geld… drie geldbiljetten."
T9	"Oh, ja"
T10	"En een wapen."
…	…
T10	"Ik hoor een hond blaffen."
T9	"Een hond, dat is niet direct iets voor mij."
T10	"Zal ik eerst gaan?"
T9	"Ga jij maar eerst"
T10	"De hond staat daar."
T9:	"Ja, maar hij doet niets."
…	...
T10	"Ohjee, hier zit een kindje."
T9	"Het is wel vervelend dat ik jou niet door mijn…"
T10	"Hoor je mij niet?"
T9	"Ik hoor jou wel naast mij … maar ik hoor je niet door mijn microfoon"
…	...
T10	"Oh dat kind, dat steekt zijn armen in de lucht."
T9	"Doe maar rustig jongen."
T10	"We kijken gewoon even rond."

Moment 4 – 06.14-06.35	
T9	"Ik hoor je niet door de microfoon helaas, dus ik kan heel moeilijk met je praten, doordat ik je niet door mijn oortjes hoor"
Suspect	"Kom, ga weg."
T10	"Is date eh… uw zoon, mevrouw? In de andere kamer."
Suspect	"Wablief?"
T10	"Is dat jouw zoon? In de andere kamer."
Moment 5 – 06.42-07.20	
T9	"Ne maar gewoon eventjes rustig, hè? Zodat we gewoon eventjes rustig met je kunnen praten."
Suspect	"Praten, waarom praten? Iedereen moet altijd praten."
T10	"Dat er toch een aantal dingen zijn die ons een beetje verontrusten, we zien dat u een hamer vast heeft. We hebben ook al een paar hamers gezien. We hebben nog een aantal andere dingen gezien. We hebben ook een kindje gezien…"
T9	"Ja, we maken ons een beetje zorgen."
Moment 6 – 07.57-07.58	
T9	"Komt u maar mee. Loopt u maar voor."
Moment 7 – 08.39-08.55	
T9	"Hoe heet de hond?"
Suspect	"Jack."
T9	"Oh, wat een mooie naam."
T9	"Hoe oud is hij?"
…	…