Investigating the Effects of Individual Cognitive Styles on Collaborative Gameplay

SULTAN A. ALHARTHI, University of Jeddah, Saudi Arabia
GEORGE E. RAPTIS, Human Opsis, Greece
CHRISTINA KATSINI, Human Opsis, Greece
IGOR DOLGOV, New Mexico State University, USA
LENNART E. NACKE, University of Waterloo, Canada
Z O. TOUPS, New Mexico State University, USA

In multiplayer collaborative games, players need to coordinate their actions and synchronize their efforts effectively to succeed as a team; thus, individual differences can impact teamwork and gameplay. This paper investigates the effects of cognitive styles on teams engaged in collaborative gaming activities. Fifty-four individuals took part in a mixed-methods user study; they were classified as field-dependent (FD) or independent (FI) based on a field-dependent–independent (FD-I) cognitive-style-elicitation instrument. Three groups of teams were formed, based on the cognitive style of each team member: FD-FD, FD-FI, FI-FI. We examined collaborative gameplay in terms of team performance, cognitive load, communication, and player experience. The analysis revealed that FD-I cognitive style affected the performance and mental load of teams. We expect the findings to provide useful insights on understanding how cognitive styles influence collaborative gameplay.

CCS Concepts: • **Applied computing** → **Computer games**; • **Human-centered computing** → **HCI theory, concepts and models**; Empirical studies in HCI; • **Information systems** → *Collaborative and social computing systems and tools*; *Massively multiplayer online games*;

Additional Key Words and Phrases: Cognitive styles, teams, teamwork, team coordination, collaboration, multiplayer games, gameplay.

ACM Reference Format:
Sultan A. Alharthi, George E. Raptis, Christina Katsini, Igor Dolgov, Lennart E. Nacke, and Z O. Toups. 2021. Investigating the Effects of Individual Cognitive Styles on Collaborative Gameplay. *ACM Trans. Comput.-Hum. Interact.* 28, 4, Article 1 (August 2021), 48 pages. https://doi.org/10.1145/3445792

1 INTRODUCTION

In multiplayer collaborative games, players need to continually work together to succeed as a team in accomplishing game objectives. This is achieved by players processing and exchanging information among team members through the game interface [202]. However, according to several socio-cognitive theories, people develop different cognitive styles that influence the way they

Authors' addresses: Sultan A. Alharthi, University of Jeddah, P.O. Box 30001, MSC CS, Jeddah, NM, 88003, Saudi Arabia, sultan.alharthi@acm.org; George E. Raptis, Human Opsis, Patras, Greece, raptisg@upnet.gr; Christina Katsini, Human Opsis, Patras, Greece, katsinic@upnet.gr; Igor Dolgov, New Mexico State University, P.O. Box 30001, MSC CS, Las Cruces, NM, 88003, USA, id@nmsu.edu; Lennart E. Nacke, University of Waterloo, Waterloo, Canada, lennart.nacke@acm.org; Z O. Toups, New Mexico State University, P.O. Box 30001, MSC CS, Las Cruces, NM, 88003, USA, z@cs.nmsu.edu.

1073-0516/2021/8-ART1 $15.00
https://doi.org/10.1145/3445792

process and exchange information. Thus, these differences could have an impact on the gameplay behavior and experience.

Cognitive styles are considered higher-level cognitive functions representing the typical mode of thinking, remembering, and problem-solving, which an individual prefers and tends to follow to process information [108]. Cognitive styles, which are also considered as intellectual executive functions [75], describe consistencies in an individual's manner for acquiring and processing information and differences in executive functioning and cognitive skills and abilities are expected to be reflected in varying cognitive style dimensions [108]. Considering that people with disparate cognitive styles process information differently and that each team member introduces their cognitive style's unique characteristics to the team, individual cognitive styles are expected to play an important role in how teams experience collaborative gameplay.

While there is a growing body of research investigating different aspects that are central to this work, such as collaborative gameplay [9, 114, 178, 183, 202, 203], impact of cognitive characteristics on games [71, 72, 168, 170], and impact of cognitive styles on single-player games [87, 110, 150, 153], to our knowledge, scholars have not yet examined the effects of cognitive styles on collaborative gameplay. This paper investigates the impact of an accredited cognitive style (Field Dependence-Independence) on the gameplay behavior of teams with varying cognitive profiles while playing a well-researched distributed multiplayer collaborative game (*TeCP*).

Through a mixed-methods between-subjects study, we empirically evaluate how cognitive styles influence various gameplay dimensions, such as team performance, cognitive workload, player experience, communication, gameworld exploration strategy, navigation approaches, and interaction styles. The results show that the diversity of team members regarding their cognitive styles has an impact on collaborative gameplay, influencing a variety of teamwork dimensions. These findings suggest that cognitive styles should be considered as one of the human factors to support and improve teamwork effort. Players who face difficulties processing information in time-dependent tasks and demanding/stressful contexts should be efficiently supported by game design elements. We expect our findings to provide useful insights for designers, practitioners, researchers, and implications for the HCI, CSCW, and gaming communities on improving teamwork.

1.1 Contribution

While several socio-cognitive theories suggest that cognitive styles influence the way people acquire information, process and apply knowledge, and make decisions, they do not provide us with enough insights into how cognitive styles affect gameplay in collaborative environments (e.g., multiplayer games). This work contributes to the understanding of cognitive styles and teamwork by providing empirical evidence and new insights on the effects of cognitive styles on collaborative gameplay, how they impact team performance, cognitive workload, gameplay experience, and communication. Our research presents a discussion about how differences in cognitive styles influence teams' exploration strategies, problem-solving approaches, interaction styles, communication, and navigation. It also contributes a set of design implications on how future multiplayer games can be designed to accommodate differences in players' cognitive styles to support better teamwork. We extend prior work on both collaborative games and cognitive styles and create a bridge between these two research domains, helping researchers, designers, and the gaming community to make better sense of how different players' cognitive styles may influence their gameplay behavior and teamwork.

1.2 Article Organization

We begin the article by discussing background on cognitive styles, collaboration and teamwork, and games and collaborative gameplay. We then explain the research artifact, the *Team Coordination*

& Planning Game (TeCP) that we used in this study. A methodology section explains our study process, including ethical considerations, recruitment, participant, experimental design, measures, apparatus, study protocol, and analysis method. From there, we develop both quantitative and qualitative results that highlight how cognitive styles influence teamwork and how performance, workload, player experience, and communication differ between players and teams. Finally, we conclude this work with a discussion and develop design implications based on the results of our study and highlight the limitations of this work.

2 BACKGROUND

In this section, we synthesize prior research on cognitive styles, collaboration and teamwork, and games and collaborative gameplay. This background section is intended to provide both breadth and depth across the range of topics that are central to this work, enabling readers to make sense of the past and current research efforts within the domains of these topics.

2.1 Cognitive Styles

Several socio-cognitive theories [108, 157, 175] suggest that people differ in the way they seek, represent, process, and retrieve information, depending on their cognitive characteristics, such as cognitive abilities/skills (i.e., the ability to learn, to process and apply knowledge, to analyze, to reason, to evaluate and to decide) and cognitive styles (i.e., the typical mode of thinking, remembering or problem-solving, which refer to the preferred way of processing information). Unlike cognitive abilities, which are typically unipolar (i.e., ranging from zero to a maximum value), cognitive styles are multi-polar dimensions. They denote a tendency to behave in a certain manner, and thus, several researchers [11, 106, 157, 201] have used cognitive styles to explain empirically the observed differences in the way people process information. Extensive research efforts have reported that differences in cognitive styles have an impact on individuals' performance, experience, and teamwork, in diverse fields such as e-learning [34], cultural heritage [155], gaming [110], security [99], business and management [15], and e-commerce and marketing [118]. On the other hand, when individuals have cognitive styles that are compatible with the work they are doing, they are more likely to perform better. The mapping between the characteristics of the cognitive style and the requirements of a task can be either because of the nature of the task (e.g., an individual who has an analytical cognitive style regarding the visual search process is expected to perform better in tasks that require thorough search within a complex visual scene [136, 154]) or because the task has been adapted to the characteristics of each individual's cognitive style [99, 123, 155, 182].

2.1.1 Field Dependence-Independence (FD-I).

Several diverse cognitive styles have been identified in the literature [108, 157], such as Field Dependence-Independence [201], Visualizers-Verbalizers [143], and Holists-Serialists [146]. According to Miller's [131] and Nosal's [137] theoretical frameworks, different cognitive styles can be identified and applied at varying stages of cognitive processing, such as perception and information organization. Field Dependence-Independence (FD-I) is the most prominent cognitive style regarding the perception dimensions of cognitive processing [131, 137], such as selective attention and field structuring, which is often triggered in video games that are built on scenes and virtual worlds with rich visual content that the players must process to have a better understanding of the game and complete the game objectives. FD-I cognitive style is an established and validated single-dimension style that characterizes people as either field-dependent (FD) or field-independent (FI), based on their ability to extract visual information in complex scenes [55, 201]. FI-style people disentangle a field into its components, isolate important information from a complex whole, and are not influenced by the perceptual field, while FD-style people tend to see the perceptual field as a whole, process information globally, and are less attentive to detail. When searching for visual cues FD-style people tend to follow a more holistic strategy and have a more disoriented visual behavior starting from the outer regions of the scene and ending up in the details. On the other hand, FI-style people tend to identify critical cues quickly and adopt an analytic approach by following specific distinct scene characteristics, such as shapes and colors. Figure 1 depicts an example of a visual search task, where people need to find a simple image (left panel: top shape) within a complex image (left panel: middle shape). FI-style people (right panel: bottom lane) tend to start their visual exploration approach by identifying distinct characteristics (e.g., edges), continue with critical cues (e.g., smaller shapes), and gradually explore the whole visual scene following a sequential approach. On the other hand, FD-style people (right panel: top lane) tend to identify outer parts of the visual scene and explore it in a more disoriented way, without following a specific pattern.

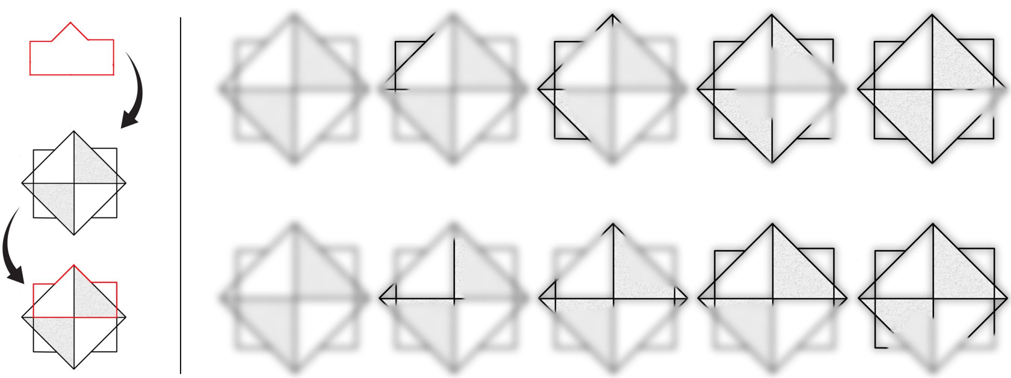


Fig. 1. In visual search tasks (e.g., left panel: people need to identify a simple image within a complex image), FD-style and FI-style people follow different strategies to deconstruct the visual scenes, with FD=style people adopting a more holistic and disoriented approach (top) and FI-style people following a more analytic approach by identifying details and following distinct scene characteristics (e.g., shapes) [149].

Research has shown that FD-style people tend to prefer a personal orientation, be holistic, have difficulties in distinguishing details from other information [199], perform better on inductive tasks [108], and rely on external frames of reference [130]. FD-style people are more focused on an overall goal and are affected by external structure [112]. They thus have a higher frustration tolerance than FI-style people [32]. FI-style people tend to prefer an impersonal orientation, be analytical, pay attention to details, and easily separate simple elements and structures from surrounding context [108, 130, 199]. Research has shown that, in solo activities, FI-style people are better than FD-style ones when performing visual search tasks [150], which can be affected by several factors such as scene complexity [99] and scene visual depth [151]. FI-style people perform better in tasks that require an analytic information-processing approach, such as puzzle-solving [87], and visual decision making tasks [127]. In such types of tasks, they tend to develop more creative [136] and exploratory [153] problem-solving strategies.

2.1.2 FD-I measurement and stability. A number of methods have been proposed to measure FD-I cognitive style, the most popular ones are: Group Embedded Figures Test (GEFT) [140], Hidden Figures Test (HFT), and Rod-and-Frame Test (RFT) [139]. Several studies have investigated the reliability of these methods across different groups regarding age, sex, and cultural background [22, 100, 102]; based on their findings several group-specific tools have been proposed, such as Preschool Embedded Figures Test (PEFT) [38] and Children Embedded Figures Test (CEFT) [97].

Cognitive styles are generally referred to as stable characteristics [129] that are hardly changed by human activity [157]. Regarding FD-I, extensive cross-sectional research and reviews have reported a curvilinear trend with age, indicating changes regarding the performance of individuals on elicitation tools (e.g., GEFT, HFT) with age over the life-span [144, 166]. FD-I is shown to be stable [41] after adolescence [107] and young adulthood [200], which is difficult to be changed even after extensive training sessions (e.g., through game-playing) towards one or the other dimension [187]. While people can change their scores on FD-I elicitation tools, such as GEFT, only a few of them can actually change their FD-I orientation [100]. Regarding other factors, while early research had shown that men tend to be more FI, while women tend to be more FD [201], no significant sex differences on the FD-I dimension have been observed in varying age groups [144, 198]. Moreover, no prior research showed that intelligence affects the FD-I dimension [144].

2.1.3 FD-I and neuroscience. Several attempts have been made to investigate cognitive styles through neuropsychological measures [64, 65, 68, 109]. Focusing on FD-I cognitive style, studies considering cerebral functions suggest that differences between FD-style and FI-style individuals are based on differences observed in the right/left cerebral hemispheres of the brain [51, 61, 147, 176], which might reflect variations in the efficiency of cognitive processes associated with frontal lobe systems [67, 145, 192] and brain structure [81]. For example, FD-style individuals display greater between-hemisphere coherence, suggesting less hemispheric differentiation [138, 141]. Moreover, a recent study [52] revealed differences between FD-style and FI-style individuals through electroencephalography-based bistable perception processing.

2.1.4 FD-I and games. Among other factors, cognition plays an important role in defining how people choose strategies and process information when playing games. Focusing on FD-I cognitive style, research has shown that in games that include item-collection tasks, FI-style players tend to identify faster and pay longer attention to critical game items by adopting an exploratory strategy [152], while FD-style players tend to focus on the game objectives and strictly follow the rules. Such differences could lead to imbalances between FD-style and FI-style players regarding various gaming aspects, such as experience (e.g., FI-style players are more immersed [151]), completion time (e.g., FD-style players complete the game faster [153]), and learning outcome (e.g., FI-style players have a better comprehension as they interact with more game items[152]). These phenomena are more intense in environments that are based on scenes with rich visual content, such as virtual-reality and augmented-reality contexts [84, 151]. In games that include pattern recognition tasks, such as jigsaw puzzles, FD-style players tend to be distracted by irrelevant environment cues while FI-style players tend to be more focused and more accurate, and thus, FI-style players perform fewer actions to complete the tasks while FD-style players need more time to process visual information and solve visual problems [87]. While FD-I had an impact on players' performance it slightly affected their strategy as they both preferred a strategy built on analogical thinking.

In games that require users to quickly process visual information in order to make decisions (e.g., sports games), FD-style players tend to demonstrate a general reluctance towards games with increased perceived complexity, games that require difficult handling, or games that are based on operations (e.g., gestures) that the players are not familiar with [127]. Instructional games are shown to help FI-style players when they are based on exploratory tasks (e.g., players are free to visually explore cards with text and pictures to connect stories in a game) [28], while such games help FD-style players to perform better when they are required to strictly follow a specific process to accomplish game objectives (e.g., follow specific steps in specific order to build a story) [195]. Moreover, FI-style players seem to be more flexible in changing their gaming strategies to accomplish their goals [88].

These prior studies focused on single-player games while, to the authors' knowledge, only a few works have considered investigating the effect of FD-I cognitive style on multiplayer games. Lu et al. [120] showed that when the game supports different strategies, it is beneficial for teams with FD-style players in handling effective problem-solving strategies. Chang et al. [32] showed that in a multilateral competition game, FI-style players were less influenced by their peers and paid more attention on the gaming activity while FD-style players relied more on external frames of reference and enjoyed the social interaction with their peers. While both works [32, 120] provide valuable insights, they mainly focus on competitive games. Horak [88] showed that teams whose aggregated cognitive style was towards FI direction changed their approach during the game; however, the gameplay aspect was not studied and the sample size was small (2 teams). All of these prior works provide some insights, but they do not study the influence of cognitive styles on collaborative gameplay.

2.1.5 FD-I and Collaboration. Little work has considered the interplay between FD-I cognitive style and collaboration. Research has shown that FD-I heterogeneity can be beneficial [113] as people in heterogeneous groups have the opportunity to learn from each other, but homogeneity can preserve team harmony and productivity [189], which however might cause conflict concerning role assignments [113]; FD-style learners get greater benefits from the cognitive apprenticeship model via collaborative web-based learning [112]; FD-style individuals prefer working in groups, whereas FI-style individuals prefer working alone during learning processes [163]; FD-style individuals are more task-oriented than FI-style individuals in a group setting [74]; FI-style individuals seem to have more the role of a leader, while FD-style individuals seem to have more the role of a counsellor taking advantage of their interpersonal skills [128]; team heterogeneity, in terms of mentor and learner, is beneficial for performance in educational settings [60]; FI-FI dyads are more effective than FD-FD dyads when performing word-guessing tasks [57]. These prior literature are limited to learning contexts and they focus on team performance and do not investigate other team principles such as collaboration. The present work expands our understanding of this space.

2.2 Collaboration and Teamwork

Central to collaboration is the concepts of *teams* and *teamwork*. A *team* can be defined as a group of two or more actors (people, animals, robots) who are assigned different roles and *collaborate* to achieve a shared goal [161]. In *teamwork*, performance can be maximized when teams are able to organize their activities, synchronize their effort, communicate and coordinate effectively, and maintain shared mental models and situation awareness [2, 47, 62, 78].

2.2.1 Collaboration. Effective collaboration is essential to successful teamwork. User interfaces in games include techniques for supporting both human-computer interaction and human-human interaction [178]. In distributed multiplayer games, these two modes of interaction can not be separated. For example, when playing a multiplayer game (e.g., *Fortnite* [49]), the direct collaboration with a player is mediated by the collaboration and communication tools available within the *gameworld*—the interface of the game. When such tools are designed to provide players with enough communication and collaboration support, players can engage in teamwork. Thus, understanding how players communicate and interact in multiplayer games can help us design better games that support teamwork [202].

2.2.2 Team Cognition. Individuals and teams perform different cognitive activities such as acquiring and processing information, making sense and assessing situations and making decisions. *Team cognition* is the cognitive activity that happens at a team level [77]. In teamwork, both individual and team cognition happen simultaneously. Prior studies and research recognize that individual knowledge and skills influence how individuals and teams work together [37, 77, 85, 179, 202]. When individual knowledge and skills are distributed across team members, they effectively contribute to a better team cognition and perform better as a team [85]. Effective team cognition may include activities such as understanding what is happening in the environment, utilizing both verbal and non-verbal cues [77, 202], establishing a common ground [37], maintaining situation awareness [47], and communicating effectively [179]. Collective information seeking, communication, and awareness play an important part in supporting teamwork.

Collective information seeking is an essential part of the process of understanding and making sense of situations as a team [197]. It involves collecting, filtering, processing, authenticating, interpreting, and sharing information that is needed to understand a situation [2]. Individuals and teams develop different cognitive skills and styles in acquiring and processing such information, hence individual differences in cognitive style and the ability to extract information in complex scenes have the potential to impact teamwork [150, 153, 197, 201].

A mental model is a way in which individuals understand how something works in the real world, a representation of an object or process in an individual or team mind [92]. During collaborative activity, teams plan actions by gathering relevant information, individually and collectively, analyzing information to establish a strategy, and make sense of the situation, which leads to accomplishing a shared goal [9, 202]. When mental models are shared among teammates, teams are equipped to understand and simulate the world around them in similar ways. *Shared mental models* support teams in working together efficiently by enabling them to use different types of communication modalities [16, 124, 179].

2.2.3 Team Formation. Successful teamwork relies heavily on effective cooperation between each team member, thus, team formation and team building are crucial. Team formation strategies are of interest in the context of electronic sports (*eSports*), the playing and spectating of competitive and multiplayer online games [79]. In these high-performance action teams, the collaboration between players is crucial for their overall success in the game. Teams in distributed multiplayer games, such as *Dota 2* [186], *League of Legends* [159], and *Fortnite* [49] coordinate and work under high pressure [45, 133, 134]. In such games, a team's success is predicated on their ability to coordinate as a team, that is, the accuracy of their shared mental models and their situation awareness both of their own team's functioning and of that of their opponents [70, 104, 148].

Prior literature has investigated team formation and the factors that influence a team's success, such as players' relationships and familiarity with each other [10, 45, 59, 134], personality types and attitude [26, 40], individual differences [90], collective intelligence [104], and demographic factors [95]. While these prior literature investigate how these factors influence teamwork and team formation and provide valuable insights, differences in individual cognitive styles and their impact on team formation have not been investigated in the context of collaborative gaming activities. Differences in cognitive styles are expected to play an important role in the success of teamwork in games [150, 151, 153]. While forming teams that include players with different or complementary backgrounds, play experience, and communication skills can influence teamwork, in this study, we mainly focus on how constructing teams with differences in cognitive styles may influence their collaboration and gameplay.

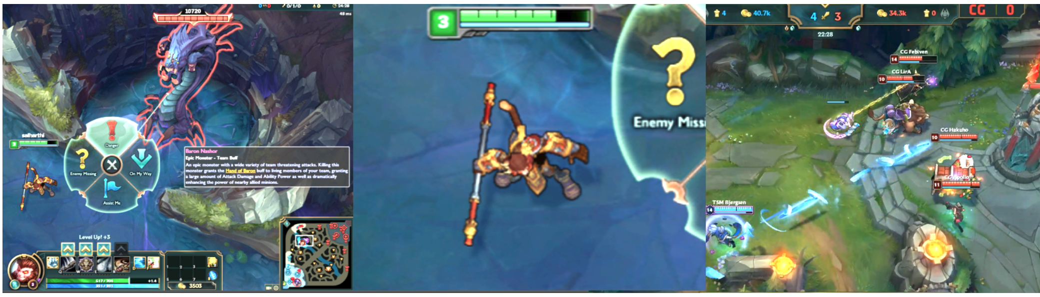


Fig. 2. Non-verbal communication mechanics and awareness cues found in collaborative games [9, 202].

2.3 Games and Collaborative Gameplay

Games are a prominent example of systems that cultivate collaborative behaviors [167, 169]. Games can be characterized as interconnected systems of *rules*, the boundaries that constrain player action, and *play*, the freedom to make decisions within the rules [162]. *Game mechanics* are the choices and actions that a player can make within the a game, which result in an observable outcome [1, 162]. *Core mechanics* are the actions that a player make repeatedly in the game, which affect the underlying subsystems of the game in important ways. *Gameworld* is defined as "an information space and an ecological environment designed with certain gameplay activities in mind" [93, p23–24]. A gameworld is a virtual space, in which players can interact with each other through their embodiment (i.e., avatars) and other available communication mechanics . The rules of the game is enforced by the gameworld, which provides a virtual boundary to the game [181].

Gameplay can be defined as "*the game dynamics emerging from the interplay between rules and game geography*" [46, p. 102]. It is the structure and interaction with the game system, elements, and other players governed by the rules and boundaries of the game [46, 86]. Zagal et al. discussed *collaborative gameplay*, in which, "*all the participants work together as a team, sharing the pay-offs and outcomes; if the team wins or loses, everyone wins or loses*" [205, p. 25]. In collaborative games, players engage in teamwork to succeed. Understanding the objectives of the game, communicating with teammates, establishing a common ground, and maintaining awareness help players to collaborate effectively [9, 178, 202]. Each team member needs to have the ability and skills to collaborate with other teammates in order to contribute productively. Individual differences in team members may influence how teams collaborate and play together, thus there is a great need to investigate how differences in players impact collaborative gameplay and how we can improve teamwork within games.

2.3.1 Explicit & Implicit Coordination. Teams communicate information to each other in virtual environments. Information such as play strategies, help and assistance, expressing frustration and joy. Effective team coordination requires teams to rely on both explicit and implicit communication modes. *Explicit* communication, such as verbal communication (e.g., go to the battle area, collect these gems, etc.) enables players to share with each other their status and enable them to coordinate their actions [122]. When teams become more experienced and efficient, they reduce their reliance on explicit communication and shift to a mode of *implicit* coordination [178, 180], which means that players are able to communicate less by making use of cues from their environment, such as non-verbal modalities and awareness information, enabling them to collaborate more efficiently [9, 114, 202].

2.3.2 Cooperative Communication Mechanics. Players communicate and coordinate explicitly and implicitly through different verbal and non-verbal channels: verbal channels such as voice or text chat [173]; and using interfaces and tools such as virtual gestures and non-verbal cues [178, 202, 203] (Figure 2). Prior literature has investigated how these different communication modalities are designed and used in games [9, 178, 183, 202, 203]. Both verbal and non-verbal communication channels are important aspects of multiplayer games, enabling players to collaborate and coordinate actions [27, 173, 193]. *Cooperative communication mechanics* (CCMs) are game mechanics that provide players with the ability to communication with each other within the gameworld [178]. Toups et al. [178] identified and classified the types of CCMs available in multiplayer and cooperative games. The CCM framework provides six trees of cooperative communication mechanic types, including *environment-modifying*, *automated communication*, *immersive*, *expressive*, *emergent*, and *attention-focusing*. All of these types help describe the ways in which games can support teams in communicating and cooperating effectively.

Pings are an example of such CCMs. Pings are visual or auditory signals that help focus a player's attention during gameplay. Pings can be placed in the gameworld or minimap and are a common method to point out and reference parts of the gameworld [114, 178, 203]. Vaddi et al. [183] investigated how such pings impact players performance in the popular cooperative game *Portal 2* [185]. The authors found that pings were important communication modality that enables players to coordinate their actions in the game. The results show that when pings are combined with verbal communication, players' performances significantly improved. Wuertz et al. [203] studied the reasons behind players usage of pings and annotations in *Dota 2* [186], a popular multiplayer game. The authors found that players use these non-verbal communication modalities for planning, issuing warnings, pointing out resources, requesting help, and venting frustration. Comparing pings to annotations, the authors found that pings are used much more than annotations. On the other hand, Leavitt et al. [114] investigated how non-verbal communication such as pings can improve players' performances in *League of Legends* [159]. The authors found that the number of pings a player creates and their performance differed significantly and are different based on the team and individual tasks and roles players engage in. The authors suggest that providing players and teams with a variety of verbal and non-verbal communication tools is important in cooperative and time-critical games.

Free-hand annotations are another form of CCMs used in the present research. These are freely drawn visual lines created on top of the gameworld [9, 50, 158, 178, 181, 203] that allow players to plan strategies, mark locations, and communicate. In our prior study [9], we investigated how free-hand annotations impact team coordination in multiplayer games. Our results suggest that non-verbal communication such as annotation interfaces helped teams engage effectively in collaborative activities, which reduced frustration, and shortened goal completion times.

While different interfaces and mechanics in games have been investigated previously for how they impact teamwork and collaboration (e.g., [9, 114, 183, 203]), human factors and individual cognitive styles' impact on teamwork in multiplayer games is unexplored. All of these prior studies show how different verbal and non-verbal communication modalities help players maintain shared awareness of teammates and communicate effectively [35, 178]. This work investigates both explicit and implicit communication modes, including verbal and non-verbal mechanics and how such interfaces can support teamwork and how they are used by players with different cognitive characteristics.

2.3.3 Team Awareness. Players need the ability to interact and collaborate with each other to share relevant information and to succeed as a team. *Situation awareness* refers to the ability to understand and make sense of the environment around us and predict its future states [47, 48, 78].

The literature on awareness is extensive in HCI and CSCW (e.g., [42, 47, 76, 78, 164]). A number of research efforts have focused on improving situation and team awareness within cooperative and multiplayer games [174, 202, 202]. For example, Teruel et al. found that collaboration within gameplay involved similar activities observed in groupware [174]. The authors developed the *Gamespace Awareness (GA)* framework that highlights how information about the present, past, and future of activities within collaborative games can be made available to other players to improve social and group dynamics. Also, Cheung et al. [35] investigated awareness cues in co-located games. The authors classified such awareness cues and provided insights into how awareness information can support teamwork and collaboration.

In our prior work [202], we build on both the workspace and gamespace awareness frameworks [76, 174] to investigate how awareness cues can be specifically designed to support team coordination in distributed multiplayer games. We argued that the design and availability of these awareness cues and interfaces impact the difficulty, symmetricity, and power within such games. Insights from our prior work suggest that awareness cues must be considered as a main factor influencing how teams are able to coordinate their actions. Such interfaces need to be designed carefully to provide players and teams with the right information that they need at the right time and in the right form to enable effective collaboration and teamwork [202].

2.4 Synthesis: Cognitive Styles and Collaborative Gameplay

Prior research has shown that FD-style and FI-style players follow different strategies during single-player games [84, 151–153]. When a game is adapted to them or when they are naturally connected to their skills, both FD-style and FI-style players tend to improve their performance and experience [155]. While collaboration has generally been studied from a cognitive style perspective, few works consider FD-I and they mainly **a)** focus on aspects other than collaborative gameplay, such as individuals' performance [60, 88], **b)** focus on contexts other than collaboration, such as multilateral competitive contexts [32], and **c)** focus on environments other than games or amusement, such as learning environments [60, 112, 113, 189]. In this paper, we investigate whether and how FD-I cognitive style influences collaborative gameplay in a multiplayer game.

Based on our motivation, FD-I theory (Section 2.1.1), and study of related works [5, 87, 130, 136, 151, 153, 199], we expect people characterized as FI-style to be beneficial to teams playing games that involve planning using visual information, as they tend to deconstruct complex scenes faster [199], follow more effective problem solving approaches by performing fewer but more accurate movements [87], adopt a more exploratory information seeking strategy [153], be more engaged in enriched visual contexts [151], have more creative thinking when performing tasks that require visual information perception [136], and have a low dependence on contextual cues and low need for visualized guiding information [130]. Moreover, FD-I influences interaction patterns [34] and performance perceptions [56], showing that FI-style individuals have increased self esteem [207], higher self efficacy [36] and self motivation [56] which affect perceived performance [29, 54].

Following from the body of knowledge discussed in the previous paragraph and that dimensions, such as performance, cognitive workload, player experience, and communication, can be used to evaluate gameplay behavior and teamwork, since they can be measured in terms of outcome, performance, motivation, workload, and team dynamic [18], we developed the following hypotheses:

- **H1**: teams that include at least one FI-style player will have increased performance.
- **H2**: teams that include at least one FI-style player will experience lower cognitive workload.
- **H3**: teams that include at least one FI-style player will have increased player experience.
- **H4**: teams that include at least one FI-style player will communicate less.

Fig. 3. Screenshots of the Team Coordination & Planning Game (*TeCP*).

While the effectiveness of collaboration can be reflected in the metrics of our hypotheses [18], we also consider observing the behavior of FD-style and FI-style individuals when playing a multiplayer game to gain a deeper understanding of the impact of cognitive styles on collaborative gameplay. Therefore we perform both a quantitative and qualitative analyses, which are discussed in section 4. The game that was served as our research artifact is *TeCP*, which is a distributed multiplayer collaborative game that includes visual-search and collective problem-solving tasks, which are connected with perception dimensions which are interrelated with the FD-I cognitive style [131, 137]. More information about *TeCP* are provided in the next section.

3 RESEARCH ARTIFACT: *TeCP*

The *Team Coordination & Planning Game (TeCP)* is a a two-player, distributed multiplayer cooperative game, in which players must work together by communicating, planning, and annotating the game map; move around the gameworld; and manipulate objects to solve collaborative puzzles [8, 9, 177, 181]. The game was originally designed by the first author as part of his doctoral dissertation using *Unity3D*[1], a popular game-making software. During an iterative design approach, the game was constantly improved and further polished. The game was used in multiple studies by the author (e.g., [5, 8, 9]) to evaluate different types of interfaces and communication mechanics and their effect on players' performance and teamwork activities. Since this is a custom-made game, we were able to take advantage of Unity's networking capabilities to provide a reliable, low-latency connection for sending media streams, including voice and text chat, players' progress data, shared annotations, and players actions. This gave us the freedom to design and incorporate different and novel cooperative game mechanics. The game was designed for PC platforms and players use the keyboard, mouse, and headphone/speaker as the main input devices. In the following, we explain the design of *TeCP*, the game mechanics, and gameplay (Figures 3, 4, 5).

The design of the game was originally informed by our prior research [177], in which we developed a set of game design patterns intended to engage players in *disaster-response-style*

[1]https://unity.com

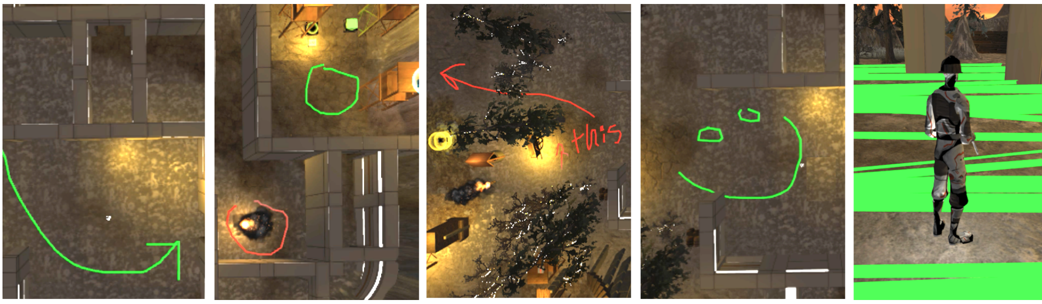


Fig. 4. Examples of the different ways in which annotations can be used during gameplay. From left to right: real-time way-guiding in the gameworld and map, using annotations to mark locations and objects on the map, player's handwriting message on the map, using annotation to express emotions, using annotations for spamming or disruptive behavior [9].

teamwork [3, 4, 7]. *Game design patterns* support the creation of games with a vocabulary that allows us to analyze them [19]. Patterns describe replicable combinations of rules and game mechanics that serve a specific purpose in a design. The *TeCP* game makes use of the following game design patterns:

- Collaborative Planning: Players within these games need to be able to interact spatially with a map to plan future activities that will be undertaken by team members.
- Emergent Objectives: Objectives in collaborative games need to be discovered, developed, or lost by players while particular game scenarios play out. Within such games, it is not necessarily for all objectives to be accomplished at the end of the game.
- Developing Intelligence: Team members should work together to make informed decisions and be able to collect information and make sense of them collectively to develop intelligence.

3.1 Game Mechanics

In *TeCP*, players move their avatars through a dungeon-like gameworld. Players need to communicate and plan activities to complete a set of collaborative puzzles. The game develops the following mechanics:

- players are able to move their avatar in all directions, subject to gravity;
- carry, place, and stack cubes handled by the avatar of the player to complete tasks;
- they can open doors or activate elevators by positioning the avatar over different buttons;
- jump on platforms that raise the avatar to higher platforms to collect out-of-reach objects;
- they can teleport through different portals to move around the gameworld; and
- switch viewpoints with the use of specific keys that toggle different game views.

To support teamwork, *TeCP* develops a set of mechanics and interfaces. In-game voice and text chat allows players to verbally communicate and send text messages to the other player in the game. Players can use these mechanics to communicate their plans and strategies to the other player. Annotation interfaces provide non-verbal communication. Players can create freehand drawings, lines and shapes by clicking and dragging the mouse cursor over the map interface in the game (Figure 4). These annotations are visible to both players in the map interface the 3D gameworld.

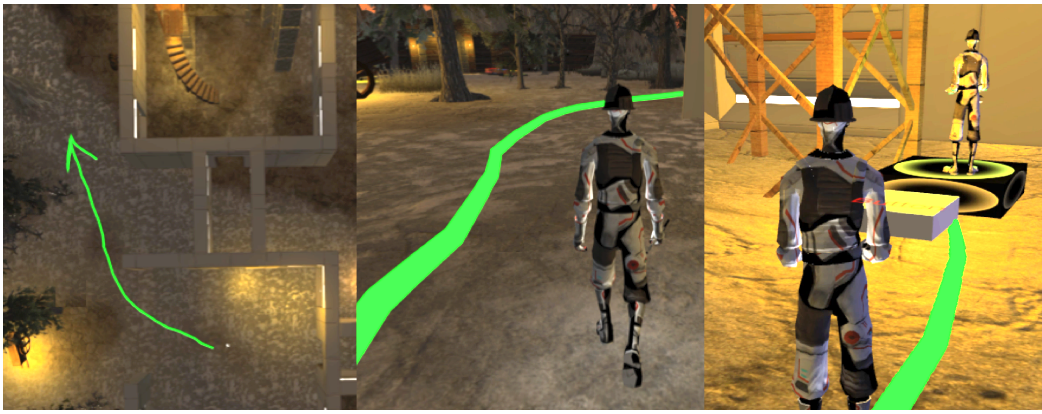


Fig. 5. To successfully finish a game level in *TeCP*, players need to collaborate to complete micro-tasks. For example, when a clue or a colored cube is found on an upper tiers, both players need to work together to collect it. They might first use the map feature to draw annotations (left) and guide/communicate with their teammates or draw a path to the elevator; annotations are visible on the top-down map (left) and the 3D gameworld (middle), where player can move in the 3D gameworld guided by the annotations (middle); when they reach the location, one player can then press the button to bring the other player on the upper tiers (right) to successfully collect the colored cube or the clue (see Figure 3).

3.2 Gameplay Scenario

At the start of the game, players are matched with a team member and are presented with a set of objectives that need to be completed (e.g., locate and place three colored cubes in their right locations). Players may start the game by collaboratively establishing a plan using the avilable cooperative interfaces and mechanics (Figure 5). The map interface available details some of the objects in the game. Players may collaboratively draw and mark the locations of the cubes on the map, draw pathways for navigating the terrain, and divide tasks between them to complete all objectives.

Dependencies in the game encourage player to coordinate and collaborate. Specific objects are specifically assigned to one of the players (e.g., cubes can only be handled by one of the players not the other); to manipulate these game objects, players need to coordinate activities and divide tasks between them accordingly. Players have the freedom to move and plan their activities and make their own decisions on which objectives needs to be completed first. This allows players to make their own discussion and plan together as a team without restrictions from the game rules.

4 METHOD

To identify the effects of FD-I cognitive style on collaborative gameplay, we conducted a mixed-methods, between-subjects study using *TeCP* as a research artifact. The study was carried out in an ecologically valid environment for game play: an internet/games café. Through this study, we empirically evaluate how FD-I influences teamwork and affects team performance, cognitive workload, experience, and communication.

4.1 Ethics and Recruitment

To insure that all the research activities of this project followed best practice, an IRB approval was obtained prior to starting the recruitment and user study. During the study, the research team followed best practice by making sure that each participant were provided with an information letter, a consent form, and an opportunity to ask any questions about the study. Participants were able to withdraw from the study at any time without any consequences of any kind.

In order to create the different types of teams (i.e., FD-FD, FD-FI, FI-FI) and to match two players with a similar or different cognitive style, a pool of participants with different cognitive styles were needed to be obtained first before creating the teams. This was done through two recruitment steps:

(1) First, we invited customers of a local internet/games café to participate in the study. Individuals who agreed to participate and provided consent were considered as potential study participants. Each participant then undertook a cognitive style elicitation test (GEFT) and their results were analyzed immediately to keep track of the distribution of participants in regards to how many participants were recruited from each cognitive style type. Once we reached a balanced number of teams, we stopped inviting people and started using these participants to form the teams.
(2) Second, we invited the participants back to the internet/games café to be teamed up with other players that either match or differ from their cognitive style. One of our aims, while creating the teams, was to match people who were not acquaintances with each other; to achieve this, the café staff helped us by indicating in our list those people who are familiar with each other, visit the café in same times and days, play different games, etc. Each team then played the *TeCP* game and completed the rest of the study (Section 4.6 and Figure 7 explain the rest of the study protocol).

However, this recruitment process posed some challenges. While we were able to invite 63 participants in this study and managed to balance the number of teams in each condition, we had to eliminate 9 participants that were no longer needed, resulting in a final sample of 54 participants. The participants that were eliminated were the last FI-style recruited individuals. We noticed that the majority of the recruited participants were identified as FI, which aligns with prior work on cognitive styles, as gamers have a tendency towards the FI dimension [23], and thus, it was challenging to find FD-style participants.

4.2 Participants

In our study, 54 customers (11 self-identified as female, 43 self-identified as male, no additional options were selected) of a local internet/games café participated. All participants were experienced video-game players (36 participants reported that they played every day, for more than 3 hours, and the rest of them reported that they played every day for 1–3 hours) and ranged in age between 18 and 30 (M = 23.2, SD = 3.7 years). All participants had experience with cooperative and competitive plays in games with similar mechanics to *TeCP*, such as *Portal 2*, *Fortnite*, and *PlayerUnknown's Battlegrounds*. Moreover, all participants had the same cultural background (i.e., residence of the same country and familiar with the local culture), they were familiar with the environment and multiplayer games, they were not aware of their partner, and they had no visual contact with them during gameplaying.

To classify the participants as either FD-style or FI-style, we used the *Group Embedded Figures Test (GEFT)* [140]. GEFT is a validated time-administered "paper and pencil" instrument that measures the ability of an individual to identify a simple figure within a complex background. Individuals are asked to identify and outline a given simple pattern in a visually complex context within a given amount of time. The test is divided into three sections. The first section is used for practice. The correct answers of the next two sections are summed to provide a raw score (range: 0–18). A common technique to classify individuals as either FD-style or FI-style is by using a cut-off score [14, 66]. The participants' GEFT scores ranged between 2 and 18 (M = 10.96, SD = 4.51, α = .89). We used the closest scale point to the mean score (i.e., 11) as a cut-off score, which has been widely

Fig. 6. A study participant plays *TeCP* at a local internet/games café.

used in practice [99, 153]. Hence, the individuals who scored 11 or less were classified as FD-style and the individuals who scored 12 or more were classified as FI-style. Based on their cognitive style, we formed three types of dyads: FD-FD (i.e., both team members were characterized as FD-style), FD-FI (i.e., one team member was characterized as FD-style and the other as FI-style), and FI-FI (i.e., both team members were characterized as FI-style), as shown in Table 1.

4.3 Experimental Design

For the current study, we used a between-subjects design with a single independent variable (IV): team type, with three levels representing the different combinations of teams and cognitive styles: FD-FD, FD-FI, FI-FI. The dependent variables (DVs) were time taken to complete the game (with a maximum of 15 minutes), scores on the workload measures, scores on the player experience, and annotation use counts (see sections 4.4 and 4.6). Regarding the qualitative analysis, we were based on post-game interviews and logs kept from observation of the video/audio recordings from the gameplay sessions (see section 4.6).

Table 1. Information about the study participants and teams.

Team	N teams	Age	GEFT score
FD-FD	9	$M = 22.9$, $SD = 3.4$	$M = 7.5$, $SD = 2.8$
FD-FI	9	$M = 22.6$, $SD = 3.6$	$M = 10.6$, $SD = 4.9$
FI-FI	9	$M = 24.1$, $SD = 4.0$	$M = 14.8$, $SD = 1.7$

4.4 Measures

To investigate the influence of cognitive styles on collaborative gameplay, we analyzed a variety of variables such as performance, workload, player experience, and communication. The rationale for these measurements is the assumption that these variables can provide an initial understanding of how cognitive styles might influence collaborative gameplaying and impact teamwork. Team work can be measured in terms of outcome, performance, motivation, workload, and team dynamic [18]. These variables are commonly evaluated through a number of methods, such as analyzing the time spent to complete a shared task, collecting and analyzing individual and team behavior, analyzing self-reported surveys, and through a combination of these instruments [18, 184, 194]. We argue that the combination of both the qualitative and quantitative measures selected in this study allowed us to gain an understanding of how cognitive styles might impact gameplay behavior and teamwork. Next, we provide details on each of the measures used in this study:

4.4.1 ***Performance.*** We use the amount of time a team needed to complete the game level as measure of efficiency and game performance. Time is a commonly used metric to evaluate performance for problem-solving and puzzle tasks [87, 153], like the tasks presented in *TeCP*. Moreover, because the goal of the game is to complete puzzles and does not use other types of scoring mechanisms, time provided a consistent way to judge performance. Time was calculated using recorded video of gameplay.

4.4.2 ***Workload.*** To assess workload, we used the NASA Task Load Index (NASA-TLX) [83], which is the most commonly used and the most widely validated tool for measuring physical and mental workload [82]. The instrument consists of six items measuring subscales of workload (i.e., mental demand, physical demand, temporal demand, performance, effort, frustration) on a 100-point scale. *Overall workload* is calculated by summing the responses of each subscale. In this study, the weighting component of NASA-TLX was omitted to reduce the time it took to complete the questionnaire. Moroney et al. [132] argue that the use of unweighted NASA-TLX scores is valid and adequate when the time is limited.

4.4.3 ***Player Experience.*** We used the Player Experience Inventory (PXI) [188] to assess player experience. This scale is designed to measure aspects of player experience in games and is based on the Mechanics-Dynamics-Aesthetics framework [89]. The PXI consists of 35 7-point Likert elements, which incorporate two subscales with multiple subfactors (Aesthetics subscale: meaning, mastery, curiosity, immersion, autonomy - Dynamics subscale: goals and rules, audiovisual appeal, challenge, ease-of-control, progress of feedback).

4.4.4 ***Non-verbal Communication.*** We counted the number of annotations made by each team to measure their non-verbal communication. Leavitt et al. [114] showed that measuring non-verbal communication can be an indication of team work. We believe that such measure can be valuable to show how cognitive styles might influence how individuals with different cognitive styles might communicate with each other.

4.5 Apparatus

The participants played the game on desktop computers (Processor: Intel Core i5-7400; Graphics Card: MSI GeForce GTX1060 3GB; RAM: 8GB DDR4) with a 22" LCD screen at resolution of 1920×1080. The computers were powerful enough to support the game and no performance issues were noted by the participants and the experimenters.

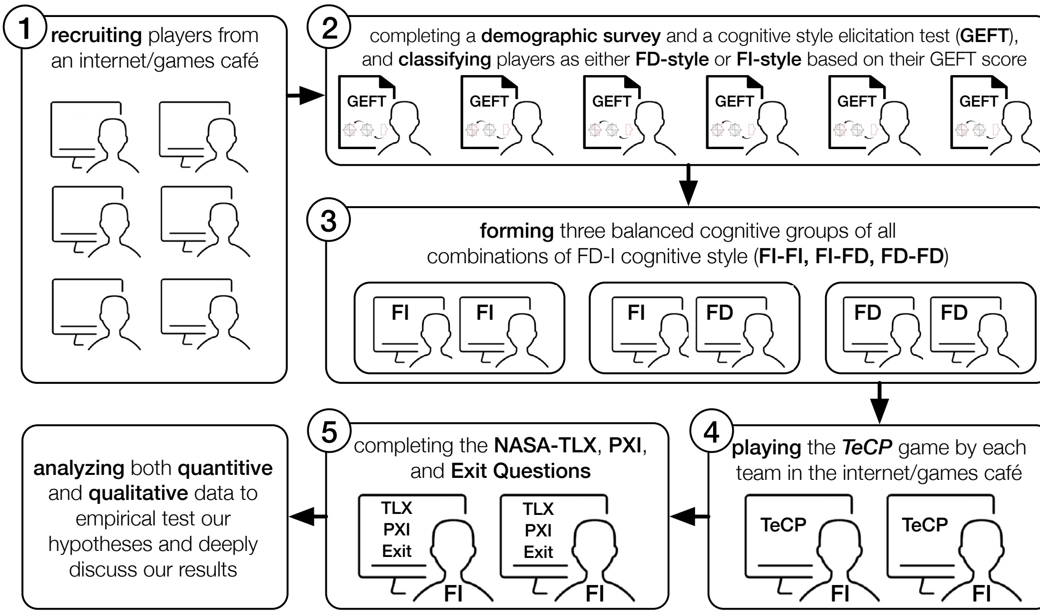


Fig. 7. Our study protocol consists of five steps: **(1)** *recruitment*, **(2)** *cognitive style elicitation*, **(3)** *team formation*, **(4)** *gameplay*, and **(5)** *post-game assessment*. When all these steps where completed, we started analyzing both the quantitative and qualitative data (see Figure 8).

4.6 Study Protocol

To summarize the process of the current study, our protocol consisted of five steps (see Figure 7):

(1) ***Recruitment***: To recruit participants, we invited customers of a local internet/games café and provided them with an overview of the study. The individuals who provided consent were considered as potential study participants.

(2) ***Cognitive style elicitation***: Each individual completed a demographics questionnaire (five minutes) and undertook GEFT (15 minutes). Once we collected each GEFT, we analyzed it following the guidelines of the scoring template, and classified the individual as either FD-style or FI-style, based on the cut-off score (i.e., 11);

(3) ***Team formation***: We aimed for a balanced study design, thus, we formed three balanced cognitive groups of all combinations of FD-I cognitive style. In total, 27 individuals characterized as FD-style and 27 individuals characterized as FI-style were randomly allocated in one of the available teams (i.e., FD-FD, FD-FI, FI-FI).

(4) ***Gameplay***: We invited each team back to the internet/games café to play the *TeCP* game (five minutes practice followed by a 15 minutes play session) at a mutually agreed day and time. Figure 6 depicts a study participant playing *TeCP*. Each participant was part of only one session in this between-subject study. All teams played the same game level with the same difficulty.

(5) ***Post-game assessment***: After the gameplay session ended, the participants completed the NASA TLX to assess workload (five minutes) and PXI to assess player experience (10 minutes). Aiming to gain qualitative insights about how the FD-I cognitive style influenced teamwork, we also asked some exit questions, following a semi-structured interview approach (see

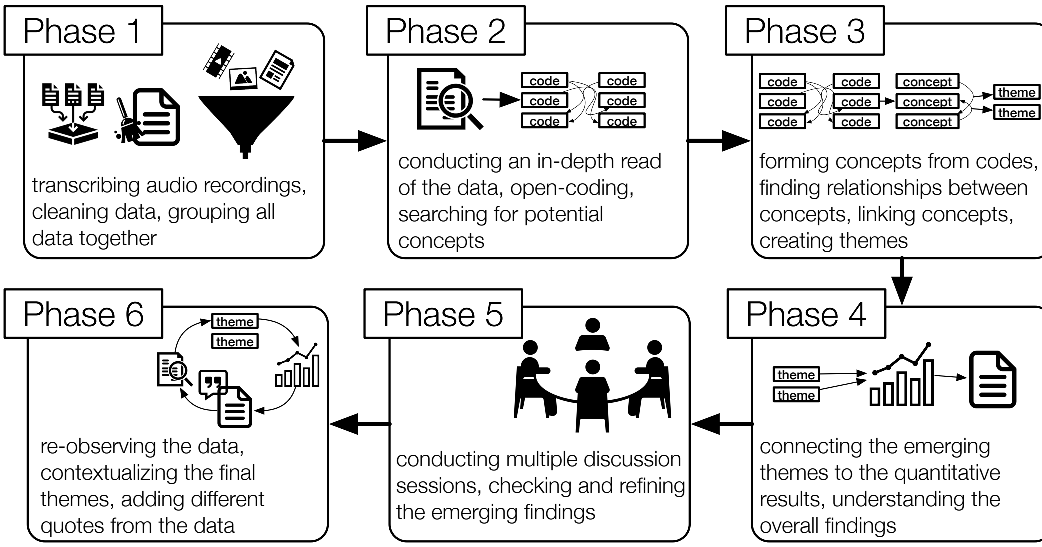


Fig. 8. Phases of the iterative data analysis approach used.

Appendix 9), to capture their perception and any comments that we were not able to capture through NASA TLX and PXI questionnaires.

The study took place at SpiderNet Internet Café in Patras, Greece during June 2018. The café provided us with specific date and time slots. Steps (1) and (2) were performed during the first three days; step (3) was performed the fourth day; and steps (4) and (5) were performed during the following ten days. When all these steps where completed, we started analyzing both the quantitative and qualitative data, which are explained in the following section.

4.7 Analysis Method

Through this mixed-methods user study, we collected valuable quantitative and qualitative data to empirical test our hypotheses and deeply discuss our results. We analyzed our qualitative data using methods drawn from *thematic analysis*, which is a set of techniques that summarize and develop insights about the characteristics of a data corpus [25]. The process consists of a series of iterative coding cycles, performed individually and collectively by the researchers, with an interest in finding commonalities within a data corpus to develop insights (see Figure 8). The data analysis was performed between June and September of 2018. The first three authors worked closely during all the phases of the data analysis and conducted multiple discussion sessions with the rest of the research team to check agreements and refine findings. The stages of thematic analysis are iterative and repeat; we employed the phases below:

Phase 1: Once all the data was collected and the audio recordings were transcribed, all data were grouped together to enable an easy coding process (this stage was done by the second and third author);

Phase 2: In-depth read of the data identified potential themes around how players coordinated their actions, the strategies and approaches they used, and the challenges they faced (e.g., *players unable to navigate*, *switching between the map and 3D gameworld constantly*, *annotating more than verbally talking*). Similar themes were grouped. (this stage was done by the first three authors);

Phase 3: When all the data were coded, part of the data were then selected to display which codes have been assigned to them. Through this process, concepts were explored and linked to create new themes. (this stage was done by the first three authors);

Phase 4: The relationships between the emergent concepts and themes were identified by the first three authors. These were then connected to the quantitative results that had been analyzed. Such connections helped to identify the main themes and better discuss our hypotheses;

Phase 5: Multiple discussion sessions between all the researchers checked agreement by discussing, refining, and improving these emerging themes.

Phase 6: While refining and constructing new categories and relationships, a final re-observation of the data was conducted by the first three authors to contextualize the final themes, situate the findings, and add different quotes from the data.

This process resulted in a set of initial codes and themes that were observed and helped us understand how cognitive styles influenced teams during collaborative gameplay. This iterative coding cycles and discussions resulted in a final set of six themes: *scene exploration strategies*, *problem-solving approaches*, *interaction styles*, *communication*, *annotation style*, and *navigation* among the different teams. We discuss in depth the results of both the quantitative and qualitative analyses in the next section.

5 RESULTS

Through this mixed-methods user study, we investigated how cognitive styles affects collaborative gameplay in a multiplayer game. In the results section, we first present our quantitative results, focusing on the analysis of team performance, cognitive workload, player experience, and non-verbal communication. Then, we discuss our qualitative results focusing on how teams played the game, how team members interacted with each other, what exploration strategies and problem-solving approaches they used, and finally how cognitive styles influenced their communication, navigation, interaction style, and overall gameplay.

5.1 Quantitative Results

We conducted one-way between-subjects analysis-of-variance (ANOVA) tests, which met all the required assumptions (unless stated otherwise in each subsection). Both objective (performance and non-verbal communication) and subjective (workload and player experience) metrics were evaluated at the team level, by averaging the scores of the team members. In this work, we focus on teamwork and collaboration and how players work together and succeed as a team, thus, our analysis both focused on looking at how each type of team experienced the gameplay and collaborated. In the next subsections, we discuss only the statistically significant effects; a detailed statistical analysis is presented in Appendix 9.

5.1.1 ***Team Performance Findings.*** All teams completed the game within time. The one-way ANOVA (IV: team type, DV: completion time) revealed that the performance was statistically significantly different for different teams ($F_{(2,24)} = 7.307$, $p = .003$, $\omega^2 = .318$). The performance was higher for FI-FI teams ($N_{teams} = 9$, $M = 402.909$, $SD = 114.591$), moderate for FD-FI teams ($N_{teams} = 9$, $M = 439.570$, $SD = 125.027$), and low for FD-FD teams ($N_{teams} = 9$, $M = 650.784$, $SD = 193.323$). The Tukey post hoc tests revealed that FD-FD teams needed 211.223 (95% CI: 36.421 to 386.012, $p = .015$) more seconds than FD-FI teams and 247.870 (95% CI: 73.082 to 422.672, $p = .004$) more seconds than FI-FI teams to complete the game (Figure 9). No significant differences found between FD-FI and FI-FI teams.

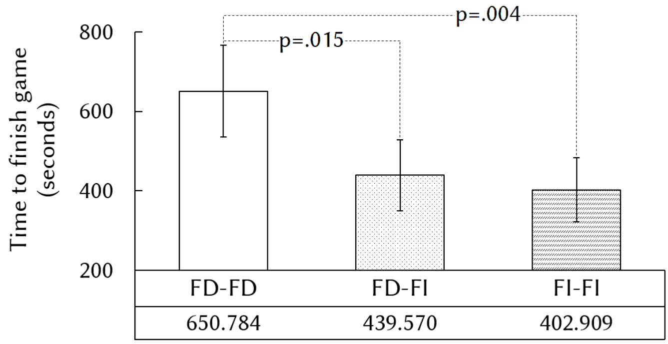
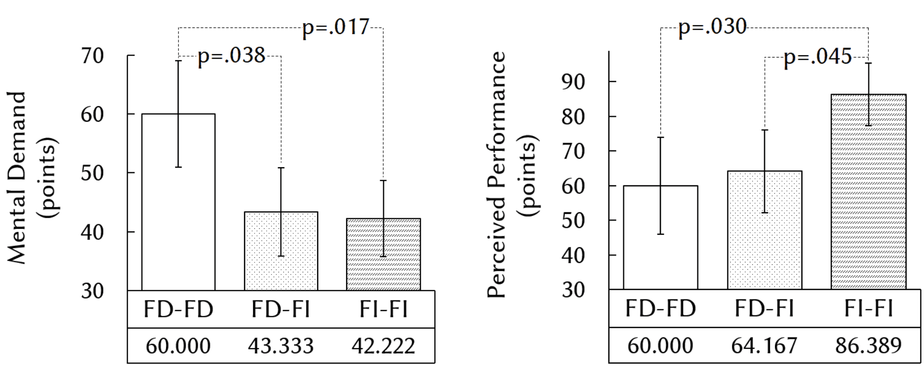


Fig. 9. Time completion of the game between each team type. Error bars show 95% confidence interval.

5.1.2 ***Cognitive Workload Findings***. The one-way ANOVA (IV: team type, DV: mental demand) showed a significant difference in *mental demand* among the teams ($F_{(2,24)} = 6.068$, $p = .007$, $\omega^2 = .274$) (Figures 10 and 11). FD-FD teams assessed the task as significantly more mentally demanding than FD-FI (16.667 points, 95% *CI*: 1.045 to 32.288, $p = .038$) and FI-FI teams (17.787 points, 95% *CI*: 3.188 to 32.368, $p = .017$). Regarding *perceived performance*, FI-FI teams reported a significantly higher score than FD-FD (26.387 points, 95% *CI*: 2.615 to 50.016, $p = .030$) and FD-FI teams (22.223 points, 95% *CI*: 0.475 to 43.970, $p = .045$). *Frustration* score was marginally different between the teams ($F_{(2,24)} = 3.327$, $p = .053$, $\omega^2 = .147$). FD-FD teams reported significantly higher frustration (26.667 points) than FI-FI teams (95% *CI*: .378 to 52.955, $p = .046$). No significant differences found between FD-FD and FD-FI teams and between FD-FI and FI-FI teams. No significant differences were found for the other dimensions of the cognitive workload.



(a) Mental Demand

(b) Perceived Performance

Fig. 10. Results on the NASA-TLX cognitive workload scale: (a). FD-FD teams assessed the tasks significantly more mentally demanding, (b). FI-FI teams had a significantly higher perceived performance. Error bars show 95% confidence interval.

5.1.3 ***Player Experience Findings***. One-way ANOVAs (IV: team type, DVs: Overall and sub-factor PXI scores) revealed no significant differences between the three teams regarding either the overall player experience or the sub-factors of dynamics and aesthetics. All teams reported high scores. Focusing on each PXI element, Kruskal-Wallis H test revealed that the *perceived playing*

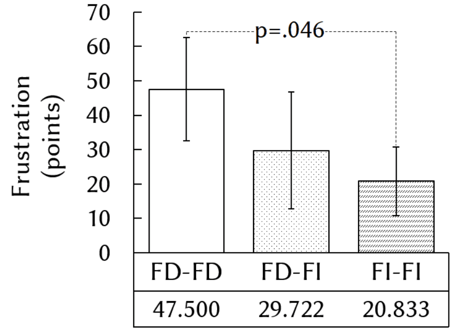


Fig. 11. Results on the NASA-TLX cognitive workload scale: FD-FD teams reported significantly higher frustration than FI-FI teams. Error bars show 95% confidence interval.

performance (element 4: "*I felt I was good at playing this game*") was statistically significantly different between teams ($H_{(2)} = 10.229$, $p = .006$). The post-hoc analysis revealed statistically significant differences in median scores between the FI-FI and FD-FD teams ($M = 4.78$ vs. $M = 3.11$, $p = .013$) and between FI-FI and FD-FI teams ($M = 4.78$ vs. $M = 3.38$, $p = .022$), with FI-FI teams reporting a higher perceived performance; this finding is in line with the finding about the perceived performance in NASA-TLX analysis. No significant differences were found for the other dimensions of the player experience.

5.1.4 ***Non-Verbal Communication Findings.*** The one-way ANOVA (IV: team type, DV: number of annotations) revealed that the number of the drawn annotations was statistically significantly different for different teams ($F_{(2,24)} = 7.858$, $p = .002$, $\omega^2 = .337$) (Figure 12). The Tukey post-hoc tests revealed that FD-FI teams drew significantly more annotations that FD-FD (2.556 more annotations, 95% *CI*: .564 to 4.547, $p = .010$) and FI-FI (2.889 more annotations, 95% *CI*: .898 to 4.880, $p = .004$) teams. No significant differences found between FD-FD and FI-FI teams. Besides the drawn annotations, all teams communicated verbally to complete the game tasks.

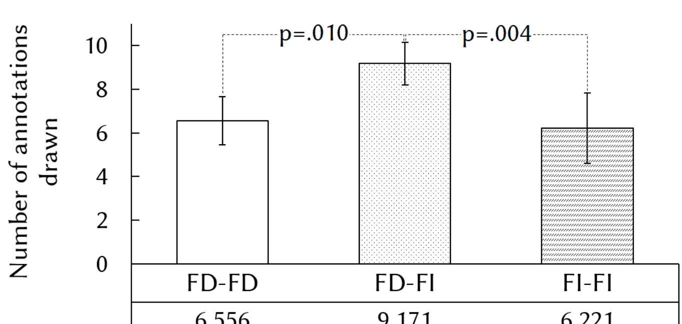


Fig. 12. Number of annotations used by each team type. FD-I teams used more annotations than FD-FD and FI-FI teams. Error bars show 95% confidence interval.

5.2 Qualitative Results

The quantitative results showed that FD-FD teams had poor performance and an increased cognitive load, FI-FI teams had a higher perceived performance, and FD-FI teams annotated more to communicate. These findings are reflected in the different observed themes: *scene exploration strategies*, *problem-solving approaches*, *interaction styles*, *communication*, *annotation style*, and *navigation* among the different teams. To interpret the results, we synthesize insights gained from exit interviews and observation of players' game activities with FD-I theory. Each theme is discussed below with illustrative quotes, labeled by participants' cognitive style, the team type and number (e.g., FD-FD team #1), and an icon which represents the source of the quote (i.e., 🎙 for the interview and 🎮 for quotes made within the gameplaying sessions). Quotes that were not made in English were translated from the original language.

5.2.1 ***Scene Exploration Strategies***. FD-I theory posits that an inherent characteristic of FD-style people is that they tend to look to other individuals when seeking information [130]. This was borne out in our study. In FD-FD teams, the individuals explored the game environment together, rather than working independently; thus, they needed more time to gather data and explore the game world. Prior research indicates that FD-style people prefer to be physically closer to those with whom they are interacting in the real world [199]. Such behavior was observed in the virtual world (for 7/9 FD-FD and 6/9 FD-FI teams), and it could be due to FD-style players facing difficulties with exploring the scene and seeking support from the other team member. As a result, in FD-FD teams, the players were aware of the interactions between their partners and the game and had a clear picture of their location and of what information they were processing.

> "*In the beginning, I felt lost and I was looking for my partner through the map.*"
>
> — 🎙 FD-style player of FD-FI team #3

> "*Don't move away; keep closer to me.*"
>
> — 🎮 FD-style player of FD-FD team #4

FI-style players, who tend to be more self-driven and motivated by self-interest [56, 207], adopted an independent exploration approach. FI-FI teams split and followed separate paths (9/9 FI-FI teams), without explicitly discussing this decision (7/9 FI-FI teams). FI-FI teams explored the scene more quickly than FD-FD teams, and thus, they had an overview of the game scene and its varying elements faster. However, considering that FI-style people tend to be more independent and not as socially aware as FD-people, effective communication within teams with at least one FI-style player is critical regarding gameplay strategy (e.g., notify their partners about what they have found) and thus the overall teamwork (see Section 5.2.4).

> "*Since we were two, the best strategy was to follow different paths and identify quickly the action areas.*"
>
> — 🎙 FI-style player of FI-FI team #8

FD-FI teams fared similarly: the FI-style player adopted a self-exploratory approach while the FD-style player was following the FI-style player (6/9 FD-FI teams) to have an improved awareness and thus an effective collaboration. This behavior is also met in other studies, in which FI-style individuals tend to develop a more leading behavior while FD-style individuals tend to be less self-interested and follow the mutually agreed strategy [128]. The FD-FI teams explored the scene faster than the FD-FD teams, probably due to the ability of FI-style players to perceive complex visual scenes and the social orientation of FD-style players (e.g., notifying their FI-style partner for what they have already visited). Since FD-FI and FI-FI teams explored more quickly the game scene, they both identified more quickly the critical areas of the scene and the actions required to complete the game tasks which contributed to better performance.

5.2.2 ***Problem-solving approaches***. Each game task (e.g., collect a cube and place it on a predefined target) was based on collaborative micro-tasks (e.g., partner A goes to an elevator and partner B presses a button to activate the elevator), which require the users to take on a specific role (e.g., giver and receiver). The faster a group assigns a role to each member and the better coordination they have, the faster they will engage in completing the task. Considering that FD-style people tend to be more sensitive to social cues and enjoy social interaction [32], they discussed the roles of each FD-FD member and mutually agreed with their partners before assigning roles (8/9 FD teams).

> "*It looks like one of us must step on the button to activate the elevator. Shall I step on the button, so that you can climb up the platform?*"
>
> — FD-style player of FD-FD team #5

Following such a strategy, both members had a clear understanding of what they were required to do, but they might needed more time to coordinate their actions. On the other hand, FI-style players, who tend to be more independent and self-instructed [199, 207], did not follow a standardized process to assign roles. They tended to adopt a *"first come, first served"* approach (e.g., the first user who steps on the elevator is the one who will climb to the platform, while the second one will activate the elevator), which is in line with the leading attitude they tend to develop [128]. This was observed for the majority of the FI-FI and FD-FI teams (8/9 and 6/9 teams respectively). While this does not account for personal preference or performance, it produced faster decisions, especially for the FD-FI teams where the roles were typically assigned by the FI-style players "on the fly" and the FD-style players adopted the assigned role.

> "*I'm on the elevator, step on the button to activate it!*"
>
> — FD-style player of FD-FI team #1

However, such behavior could be considered bossy from their partners and thus it could provoke frustration and negative feelings regarding the cooperation, leading to a poor teamwork. This could be even more evident when the partners are of FD-style and when the roles (e.g., leader, follower) are not strictly defined at the beginning of the task or not defined by the activity (e.g., game), as FD-style people tend to rely on and strictly follow the rules [108, 112]. Therefore, while mutually agreeing on the playing strategy could have an impact on performance (in terms of completion time), it could help towards avoiding misunderstandings and frustration that could lead to poor coordination and teamwork. This could be more intense in heterogeneous teams, and thus, the activity or the system (e.g., game) could nudge players towards building a clear common ground on their playing behavior.

5.2.3 ***Interaction styles***. In line with other research [108, 130, 199], FI-style players followed an analytical and exploratory approach by interacting with many game elements, regardless of being part of the game tasks. This behavior derives from FI-style people' ability to identify important aspects of visual information, especially when it is ambiguous or disorganized [136]. They followed a "trial-and-error" approach and they interacted with many items aiming to receive more information about the environment and have a clear understanding of the surrounding context. These players were often able to remember where they have previously seen important game-related information and distinguish irrelevant information, because they have the ability to pay attention to details and explore complex visual scenes and because they are typically more efficient at retrieving items from memory [12]. However, FI-style players were not notifying their partners explicitly on what they were doing and with which game assets they interacted with, and thus, it was observed that

Fig. 13. FD-FD teams used annotations to show points (left); FD-FI teams drew both paths and points (middle); FI-FI teams drew mainly paths (right).

members of FI-FI (mainly) and FD-FI teams performed duplicated interaction, which was a result of a poor collaboration on this aspect.

> "*I aimed at covering quickly the scene, so I tried to interact with what I assumed it might be part of the game, such as platforms, stairs, and fire buckets. Most of them were not parts of the game, but since I had no penalties for my decisions, I could reveal the critical parts in a few steps.*"
>
> — 🎙 FI-style player of FI-FI team #9

The fact that FI-style people interacted with many items during the game session might had a positive impact on their perceived performance and experience, as shown in other studies, while their ability to identify and interact with critical game items along with their ability to recall what is important could have an impact on the reduced mental effort. On the other hand, FD-style players were more reluctant to deviate from the information-seeking strategy agreed with their partners. They tended to stick to the activity rules and context of use and were focused on the overall game goal, which is in line with other works [108, 112]. FD-style players were more reluctant when they were uncertain about the importance of interacting with a game item on the overall game objective, and thus, they preferred not to perform unnecessary or redundant actions, unlike FI-style players, which has also been revealed in other studies [13].

> "*I was not sure whether I should select or not the cube, so I preferred to move on the game and confirm its importance later.*"
>
> — 🎙 FD-style player of FD-FI team #2

A frequent strategy that FD-style players followed when they faced difficulties on identifying interactive items or when they were not confident about the importance of the identified game items was to seek for external guidance, which was usually achieved by asking their partners (Section 5.2.4). In scenarios where an FD-style player constantly seeks for assistance from their partner, the experience, workload, and frustration could be negatively influenced for both players.

5.2.4 ***Communication***. All players and all teams used both the verbal and non-verbal channels to communicate. All players typically preferred to use the verbal communication to ask their partner a question, as it was direct and allowed them for fast decision making. In FI-FI teams, the players typically communicated to assign a role to the other player or to provide them with a clear direction of what they expect them to do. They rarely communicated to keep their partners aware of their situation, which implies a poor coordination, which however, did not affect the performance, as they were fast on visual processing and on decision making.

> *"Do you see me? Step on the platform [to help me move on]."*
>
> — FI-style player of FI-FI team #3

In FD-FI teams, FD-style players were the ones that initiated the discussion, confirming their socially sensitive nature, while FI-style players tended to act in a more isolated mode being socially aloof. There was a tendency of FD-style players to ask for clear and explicit directions and a maximum amount of guidance, which was observed mainly on FD-FI teams, because the FI-style partner seldom answered with the FD-style player's desired level of detail.

> *"I kept asking the same question again and again, because my partner provided scant feedback."*
>
> — FD-style player of FD-FI team #5

Besides the observed isolation, individualism, and rejection of social conformity by the FI-style players, research has shown that FI-style people fear the loss of control and develop a phobia of incorporation, which leads to increased distance between themselves and the group [74]. On the other hand, FD-style people prefer to depend on others for a sense of direction and support. As discussed in Gruenfeld and Lin [74], there is a conflict between FI-style and FD-style individuals in heterogeneous teams, as group participation seems to threaten the self-esteem of FI-style people, while isolation seems to threatens the self-esteem of FD-style people. Therefore, the conflicting characteristics of FD-style and FI-style players could lead to frustration and poor coordination in the heterogeneous teams, which could have a negative impact on the overall playing experience.

5.2.5 ***Use of annotations.*** Individuals used annotations to transfer knowledge about the gameworld to their partners (e.g., show an elevator, draw a path to the location they are). FD-style players typically used annotations to point a specific area of interest, while FI-style players typically used annotations to draw paths. Considering that FI-style players should be more efficient at distinguishing details in visual complex scenes [201], they communicated verbally for indicating simple gameworld elements, such as a platform or a bridge, and drew paths to direct their partners. Since FD-style players tended to physically approach their partners (as discussed in 5.2.1 section), they did not use annotations to draw paths. In FD-FI teams, both types of annotations were used, with FD-style players indicating a specific area of interest (e.g., the location they are) and FI-style players drawing paths to guide FD-style partner and accomplish a goal (e.g., path to hidden room). Figure 13 depicts such annotations. The following interaction occurred in an FD-FI group:

> FI: *"Where are you?"*
> FD: *"Here."* [FD-style player circles location]
> FI: *"Climb the platform."*
> FD: *"Which platform?"*
> FI: [FI-style player draws the path from the FD-style player's location to the platform.]
>
> — FD-FI team #2

The use of diverse types of annotations helped FD-style and FI-style people communicate in a more efficient way and overcome the potential problems that verbal communication could introduce, as discussed in section 5.2.4, and thus improve their coordination efforts. As shown in the literature, FI-style people tend to prefer a more impersonal approach [201], such as the use of nonverbal cues [69], while FD-style individuals seem to be benefited from the use of annotations [121].

5.2.6 ***Navigation styles.*** In FI-FI teams, the players explored the gameworld independently and navigated through the whole scene to build their mental models of the content. Then, they visited back each area they were interested in for a more thorough exploration, a behavior that has also been seen in other domains such as learning environments [43]. They could easily draw imaginary paths and routes by recognizing and recalling navigational structures and persistent points of reference, as it has also been seen the literature [21]. Therefore, FI-FI teams followed a more analytical approach to navigate through the scene, ensuring that they have covered most of the game world.

On the other hand, in FD-FD teams the players while working together to explore the gameworld, they followed a more dispersed navigational approach. They appeared to be more disoriented and used frequently the map feature to have a holistic overview of the gameworld. Moreover, they paid attention and focused on areas and items that they assumed that play an important role towards the game objectives. Considering that they do not perform well on extracting information from complex visual contents, their navigational approach influnced them on not exploring the system to the same extend as FI-style players, which is even more intense given the open nature of the TeCP game [43]. Therefore, we expect that their navigation style partially accounts for the observed increase in cognitive load for the FD-style players in perceiving where they are and where they must go. This is also reflected in the long completion time, despite that their approach helped them to ensure that they are on the right track.

In FD-FI teams, diverse navigation styles were observed. However, considering that FD-style players tended to follow their partners and that FI-style players had a more leading role, we could often identify characteristics of the navigation style of FI-FI teams. This style seems to have helped both members of the team, as FI-style players were naturally closer to it while FD-style players felt that they were not lost within scenes where they were facing difficulties to visually process and perceive information.

6 DISCUSSION AND DESIGN IMPLICATIONS

In this section, we revisit our hypotheses and discuss the key themes in our research, connecting our findings with prior literature and drive implications for design, practice, and research in cognitive styles and collaborative gameplay and teamwork.

6.1 Revisiting Hypotheses

We revisit our hypotheses and engage in a discussion of the main effects observed. For the discussion, we have considered the findings derived from **a)** the quantitative analysis on performance (Section 5.1.1), workload (Section 5.1.2), player experience (Section 5.1.3), and communication (Section 5.1.4), and **b)** from the qualitative analysis on scene exploration strategies (Section 5.2.1), problem-solving approaches (Section 5.2.2), interaction styles (Section 5.2.3), communication (Section 5.2.4), use of annotations (Section 5.2.5), and navigation styles (Section 5.2.6).

H1. Teams that include at least one FI-style player will have increased performance (✔ Not rejected)

Both FD-FI and FI-FI teams performed better as they completed the game in less time than FD-FD teams (statistically significant difference between FD-FI and FD-FD and between FI-FI and FD-FD teams, Section 5.1.1). In FI-FI teams, the players explored large areas of the gameworld quickly and, based on their ability to efficiently process visual information in complex scenes, they identified quickly the critical areas of the game (e.g., a hidden platform that they needed to use in order to move closer to the target). Despite the fact that they interacted with many items, which could cost them in terms of time, FI-style players could recall important information about potential critical areas, as they could use various context elements as points of reference when navigating. Another factor that might contribute to reduced completion times for FI-FI teams is that the ability of their members to extract visual information and recall important information prevailed over their isolation and independent mode of gameplaying.

In FD-FI teams, FD-style players tended to follow FI-style players when exploring the gameworld and navigating through the scenes. While this seems as a less efficient strategy than the one that FI-FI teams followed, FD-FI teams performed equally well mainly because of the effective coordination and communication plan. The main reasons that lead to this were that **a)** FI-style players assigned quickly roles to the team members, which enabled fast and accurate decision making process, **b)** FD-style players, based on their social orientation skills, kept their partners aware for their actions through a continuous dialogue mode and asked them for explict guidance to accomplish the objectives, and **c)** FD-FI players used diverse types of annotations that covered in an optimal way their teamwork effort.

On the other hand, in FD-FD teams, while the team members could coordinate their actions and their strategy, as they could explicitly discuss their roles and constantly communicate, they did not perform well in terms of completion time. They tended not to split and work independently but preferred to explore the gameworld as one, following a disoriented navigational approach, and thus, they needed more time to uncover critical game assets spread in the gameworld . Their poor performance on perceiving visual information on complex scenes along with their reluctance to interact with potential important game assets could also have an impact on their poor gameplay performance.

H2. Teams that include at least one FI-style player will experience lower cognitive workload (✔ Not rejected)

There were statistically significant differences in cognitive workload metrics (Section 5.1.2) between FI-FI and FD-FD teams (in terms of mental demand, perceived performance, and frustration) and between FD-FI and FD-FD teams (in terms of mental demand and perceived performance).

Regarding mental effort, FI-FI teams leveraged the ability of their players to perceive complex visual scenes and extract valuable information. Through their effective scene exploration and navigation strategies, they could easily identify the game targets and accomplish the game objectives. The fact that they did not use verbal communication to explicitly coordinate their plan could have an impact on the overall mental effort required to solve the game puzzles. However, they were based on explicit guidance through annotations and their ability to perceive visual information quickly to complete the game and thus they did not find the task mentally demanding.

In FD-FI teams, FI-style players worked as assistance points for FD-style players, who turned to them to make sure that they are on track and can accomplish the game objective leveraging their social orientation skills. While they had to perform searching and remembering micro-tasks, in which they are not as good as FI-style players, they relied on their team partners when facing difficulties, which contributed to a low score on mental demand. FI-style players did not work as independently as they would prefer and they were engaged in tasks that they would not naturally perform (e.g., thorough discussion to decide the game strategy), and this could be a reason for lower mental demand scores compared to FI-FI teams.

FD-FD teams faced apparent difficulties with the tasks, in terms of processing visual information, and thus they perceived the game tasks as complex goal-oriented visual tasks which make it more difficult for them to search or remember specific visual cues. Considering that increases in task demand are typically paired with increased workload rating on mental demand [196], FD-style players found the game tasks to be mentally demanding, although they followed diverse methods to better collaborate during their gameplay.

Increases in task demand are also associated with increases in frustration [196], and as a result, FD-FD teams reported higher scores regarding frustration. Even though they had a good collaboration and coordinated their actions well during the gameplay, FD-style players might felt irritated and discouraged from the fact that they could not quickly reveal important visual cues and progress the game. Regarding the heterogonous teams, we would expect to observe differences in frustration level, because of the contradicting characteristics of FD-style and FI-style people. For example, FI-style players tended to follow a more independent approach while FD-style players tended to constantly ask for explicit guidance, notify their partner about what they have performed, discuss the team strategy, etc. Therefore, these two different behaviors could be irritating for each player and thus lead to a poor gameplay behavior and teamwork effort. In accordance with this, the leadership behavior of FI-style players could annoy the FD-style players and eventually compromise the team effort. Such differences were observed in the qualitative analysis, but were not verified in the quantitative analysis.

The effects of FD-I cognitive style on perceived playing performance are discussed in the next section, as the finding from NASA-TLX scores was also revealed in PXI scores.

H3. Teams that include at least one FI-style player will have increased player experience (✖ Rejected)

There is no statistically significant difference in player experience between teams that include at least one FI-style player and those that do not (Section 5.1.3). All teams enjoyed playing the game and reported a high player experience according to PXI scores, with no statistically significant differences observed. However, a statistically significant difference regarding the perceived playing performance was revealed, with FI-FI teams reporting a higher score. FD-FD teams faced difficulties in identifying critical game assets and areas of interest, and despite the fact that they used varying means to coordinate their actions, they felt that in many times they made errors and lost time for identifying assets, which they anticipated that had a negative impact on accomplishing the game objectives and the time needed to complete the game.

Regarding FD-FI teams, while they performed well they reported a lower score on perceived performance than FI-FI teams, which could result mainly from the fact that both FD-style and FI-style players compromised with the diverse characteristics of their team members and they either were not familiar with or not felt comfortable with the mixed-style approaches they followed to coordinate the team and accomplish the game objectives. Hence, while they developed a good coordination plan with the use of multiple types of communication channels, they had the incorrect belief that they did not perform well.

On the other hand, FI-FI players reported a high perceived gameplay performance despite the fact that they often were not aware of their partners' situations (e.g., they were not aware of what game items their partners had interacted with) and that they often performed the same actions with their partners (e.g., they explored the same game scenes), as a result of not communicating for such purposes. However, being able to quickly process visual information and having increased self-esteem, self-confidence, and self-efficacy helped them perceived a higher degree of playing performance leading to good gameplay behavior and teamwork effort.

H4. Teams that include at least one FI-style player will communicate less (✖ Rejected)

We expected that in teams with FI-style players, the players will communicate less, considering that FI-style players are less socially oriented and prefer to work in isolation, which would impact various aspects of gameplay behavior, such as coordination and the teamwork effort. However, all teams used frequently both verbal and nonverbal channels to communicate their actions. In FI-FI teams, the players, who tended to work independently and follow separate paths to navigate through the scene and explore the gameworld, used the verbal channel to communicate to their team partners where they are or what they have discovered that might be important for the game progress. When they wanted to point such an area, they tended to identify their team partner on the map and design a path on how to reach their location.

In FD-FD teams, the players tended to have constant conversations about the game progress, thoroughly discuss their problem-solving approach, and role assignment. They used nonverbal communication to indicate areas of interest (e.g., an item that might be important for the game) in the map and they rarely used annotations to draw paths or show navigation patterns to their team partners. The main reasons for these are that **a)** they were following their partner and did actions together, and thus they used the annotations to point areas that they have visited before or seemed to be important (e.g., a platform), and **b)** they could not easily identify paths (e.g., identify a door that could be used to pass through another room) in visual complex scenes.

Regarding the heterogenous teams, we expected that the contradicting characteristics of FD-style and FI-style players will have a negative impact on the communication between the team members. However, the social orientation and the constant request for feedback and guidance by FD-style players triggered FI-style players to develop a more participatory behavior and to engage with the team to work together and mutually make decisions regarding how to accomplish the game objectives. An interesting finding is that FD-style and FI-style players used the nonverbal communication for different purposes and they mainly relied on the use of annotations to keep track of their game strategy. They used it more often than the other teams (Section 5.1.4) and this had a positive impact on the gameplay and teamwork effort.

6.2 Implications for Game Design

According to our results, cognitive styles influence gameplay behavior and teamwork, and thus, it should be considered as a human factor when designing multiplayer collaborative games. Teams with at least one FI-style player performed significantly better than when both team members are FD-style players. Dyads' usage of verbal and non-verbal communication mechanics enabled them to establish a shared context and enhance their ability to work as a team, which helped overcome the challenges that they faced due to their individual cognitive styles, reducing the barrier to better collaborate and coordinate their actions through the gameplay. Differences in player's cognitive styles and its impact on gameplay call for new and innovative game designs and further research efforts. In the following, we connect insights from our results to ways in which multiplayer games can be designed to support better teamwork. We provide a set of design implications for supporting design, development, and further research.

6.2.1 ***Supporting Teamwork.*** Cognitive styles influence teamwork. Prior literature suggested that there exist different factors that impact teamwork, such as team awareness [202], communication modalities [178], and skill levels [203]. We extend this prior literature by empirically showing how cognitive styles impact teamwork, how team players work with each other, how their performance, cognitive load, experience, and communication are influenced by the differences in teams' cognitive characteristics.

Our results show that team members utilized multiple types of communication modalities to perform various gameplay actions, such as to coordinate movements and explore the game scene. These results are in line with prior research that suggested to support teamwork in games, a variety of communication modalities need to be made available for players to utilize [9, 202]. However, we observed that there exist some differences in how players with different cognitive styles use these available communication modalities. Some players tend to use verbal communication more than non-verbal. This is not limited to the unique cognitive style of each player, but it also depends on the cognitive profile of the team, combining the individual cognitive styles of the team members (e.g., heterogeneous versus homogeneous teams). Designers need to provide players and teams with a variety of verbal and non-verbal communication modalities and cartography mechanics [181] to accommodate the differences in how players cooperate, which can help teams work together effectively.

Cognitive styles in teams can be taken into consideration as a main factor in player-centred game designs [171]. Designing game roles based on the cognitive style, creating combinations of such roles and using game mechanics that favor FI-style and FD-style players could unfold a whole new path for the game designers, where in-game goals require synthesizing the players' differentiated characteristics. This approach can support teamwork through assigning different unique roles to team members. These roles can take into consideration the differences in player's cognitive characteristics and match it with game activities that can be suitable for such player. For example, in many cooperative games (e.g., *Dota 2* [186]) a player can serve as a healer, a character that focuses on following team members and restoring their resources and health [202]. Such role can be suitable for players that face difficulties in navigating complex scenes without following others, increasing their enjoyment and engagement in the game. Such diverse roles within multiplayer games give players the ability to select their preferred play style and which types of gameplay activities match their abilities, thus help teams divide their efforts and collaborate effectively.

Collaborative games can also provide players with rewards or challenges that encourage them to stay in close proximity of each other as a team, enabling players who are facing difficulties navigating complex scenes alone to follow and mimic their close by team members. Moreover, we should stress that designing to support effective teamwork should not only focus on the characteristics that the cognitive style of each player brings in the team, but, it should also consider the team as a whole in terms of the combined cognitive profile. Heterogeneous (e.g., FD-FI) and homogeneous (e.g., FD-FD) teams are not only characterized by the individual cognitive style of their players, but also build new dynamics based on the combined cognitive profile, which can be complementary in some cases, improving teamwork, and in other cases, making effective teamwork difficult.

6.2.2 ***Designing for Cognitive Differences.*** Understanding the differences in players' cognitive styles have the potential to provide insights into finding new solutions and design choices to improve teamwork in games [53]. Cognitive workload differs between players. The ability to offload some of the demanding cognitive activities into the gameworld or other players can help teams collaborate effectively. This can be done using different interfaces, such as annotation interfaces [9]. Our results showed that some teams efficiently processed visual information in the complex scenes of the game (i.e., teams that had at least one FI-style player), and others did not (i.e., teams that were based on FD-style players only). Some players were able to easily recall important information about critical areas in the game through using various context elements as points of reference when navigating. Multiplayer games need to make it possible for players to use elements from the gameworld as reference points, helping teams to collaborate better and improve their gameplay [181].

Multiplayer games also need to consider players' different information-seeking and collaboration skills, offering alternative means for players to gather and share data. Our results show that dyads' use of annotations and non-verbal communications enabled them to work as a team and overcome the challenges that they faced because of their individual cognitive styles. Games could provide *automated navigation assistance*, in the form of visual annotations, to help teams reach game objectives and identify different aspects of the gameworld when needed. Johanson et al. [91] investigated such automated navigation assistance mechanics in games and how they effect spatial tasks and performance in games. Such assistance shown to be effective in improving spatial understanding in games [91], and thus, adaptable games can provide such mechanics tailored to orientation- and navigation- related cognitive styles (e.g., spatial visualizers [20]).

6.2.3 ***Reducing the Gap between Players Differences***.
Designer's choices of interfaces, mechanics, and visual elements in game scenes (e.g., images/textures) influence information seeking and collaboration behaviors of players with different cognitive styles, affecting how players work together and experience the gameplay. For example, FD-style players face difficulties in games like *TeCP* that include enriched visual contexts and find cognitively demanding the visual search tasks in such contexts. Players' difficulties originate in their intrinsic characteristics and the fact that the game designers do not consider them as design factors negatively influences the performance, workload, and experience of the team. To actively engage FD-style players in such contexts, assistive mechanisms and visualization techniques that favor FD-style players should be considered, such as scenes of low complexity/entropy [99], light recoloring [44], and saliency filters [103]. A straightforward modification to *TeCP* to have a less cluttered map interface, for example, might even the field.

Accommodating differences in players' cognitive styles and reducing the gap between players and teams has the potential to support better collaborative gameplay and improve teamwork in multiplayer games. One way is to reconsider how teams are built and how players are matched with each other. Matchmaking (i.e., the process of connecting players together for online play sessions) is an important factor for player experience and team performance. Current matchmaking services in multiplayer games are based on varying factors such player ranking and performance on the game [190], player's skills [191], physical abilities [63], latency-aware factors [206], and personality type [31], aiming to provide balance and fairness. Considering that each team member influences how the team performs [30], cognitive styles could be considered as a matchmaking and balancing factor, so that the team benefits from a variety of styles. For example, in games that require that players process complex visual information (e.g., puzzles, mazes) and connect different parts of the game (e.g., discuss what they know about a game object, predict game story), a dyad of FD-style and FI-style players is expected to perform best. Hence, if an FD-style player has joined the team, the matchmaking service should assign the free position to an FI-style player. In competitive contexts, cognitive style should also be considered as a matchmaking factor aiming to create balanced and fair teams which compete each other. However, more research should consider whither matchmaking players based on their cognitive characteristics would be different than matching them based on their skill level or past performance.

6.3 Implications Beyond Games

While our work focuses on cognitive styles in multiplayer collaborative games, we expect that insights from our findings to have implications beyond games.

6.3.1 ***Cognition-based interventions in collaborative contexts***.
We expect that cognition-based interventions in collaborative contexts would benefit the teams in terms of performance and experience, especially in cognitively demanding tasks that require fast and accurate decisions. In some time-critical domains [33, 73], the goal of visualization techniques and assistive mechanisms is to minimize the cognitive load and help people make quick and accurate decisions on their tasks objectives. In such stressful and demanding conditions, people with diverse cognitive characteristics often need to collaborate to accomplish the task objectives. Considering cognitive styles as a human factor for forming the teams, for coordinating the team, for assigning collaborative tasks, and for assigning roles to each team member, would help the team to optimize its performance and minimize the risk of failure.

6.3.2 ***Implicit elicitation of cognitive styles***.
Studies like the reported one raise the practicality of designing interactive systems that are adaptable to users' cognitive characteristics. However, this raises the challenge of eliciting such cognitive characteristics in run time, because the current

methods are based on tools, such as GEFT, that take time, need human intervention, and are typically irrelevant to the context of the designed activities. Recent studies have revealed that implicit and unobtrusive elicitation of cognitive factors is feasible through rules-based user-modeling either in time (e.g., first minute of activity) [98] or in segments (e.g., after the first microtask) [156]. Therefore, the transparent elicitation of cognitive styles in run-time would enable the providers (e.g., online multiplayer game platforms) to adapt their services seamlessly and with minimum latency, tailored to the cognitive characteristics of the team.

6.4 Implications for Future Research

Our work has implications for future research and researchers who are interested in understanding the impact of cognitive styles on teamwork in games and beyond. We see this paper as a starting point for research that investigates the impact of cognitive styles on teamwork. Researchers can extend our work to other domains of teamwork (e.g., learning, disaster response, sports [58, 101]) and further investigate the influence of other cognitive characteristics and human factors (e.g., collective intelligence [104], personality traits [94]) on teamwork. More research connecting cognitive styles with teamwork will in fact be necessary to refine, confirm, and further elaborate our novel findings.

6.4.1 ***Teamwork and Collaboration.*** Researchers working on topics related to teamwork and collaboration need to investigate new and novel approaches to better support teamwork through system design. Based on the results of our work, researchers can begin to describe existing and new set of designs that supports teamwork and conduct further investigation on how these designs might support teams in working effectively. Future directions could look at how the choices of interfaces, mechanics, and visual elements in games and other software (e.g., images/textures) influence information seeking, collaboration performance, and behaviors of individuals and teams with different cognitive styles. Insights from our work could guide the design of interfaces and mechanics, such as cooperative communication mechanics [9, 178], awareness cues [202], and textures, that accommodate the differences in users' cognitive styles, helping to improve collaboration. In this work, we focused on dyadic teams, however further research could extend our work and investigate how such cognitive differences influence teamwork within larger teams (e.g., triads, tetrads).

6.4.2 ***Cognitive Styles.*** Future work will also look at analyzing other cognitive styles (e.g., Convergent vs. Divergent individuals to explore memory retrieval dimensions [131]) and user preferences and characteristics (e.g., personality traits [94], video game preference [204], and skill and expertise [165]) and how they influence collaboration skills and teamwork in games and other domains. We also expect that certain interfaces and designs can be utilized as a mechanism for determining a player's cognitive style, replacing the GEFT instrument and enabling the use of cognitive styles as part of players matchmaking within multiplayer games. We also see an opportunity to extend this work by investigating whither game-specific training can influence a player cognitive style, changing a player ability to distinguish elements in complex scenes and influence their information seeking and collaboration skills.

7 STUDY VALIDITY AND LIMITATIONS

In this section we discuss the validity of our study, including *internal*, *external*, and *ecological* validity. We also highlight the limitations of this work and discuss how social presence of other players, cultural differences between players, and differences in skill levels may have influenced the results of our work and how future work could extend and build on our findings.

7.1 Internal, External, and Ecological Validity

Regarding the internal validity, the study environment and the study procedure remained the same for all participants. The methodology and statistical tests used to answer the research objectives met all the required assumptions. Focusing on the study instruments, we used GEFT [140] to classify an individual's cognitive style as FD or FI, based on a cut-off score. Considering that GEFT highlights cognitive differences along a continuum scale, the use of a cut-off score might not classify correctly individuals that fall in between the two end-points; thus, various alternative classification techniques have been proposed [39, 117] and several studies [12, 14, 17] use a third dimension called "field-mixed" to characterize individuals with a GEFT score close to the mean score of the study sample. Considering our limited sample size, we followed a dichotomous approach, which adopts the mean score as the cut-off score and has been efficiently used in practice [87, 99, 126, 153].

Regarding the external validity, our sample size was limited for the quantitative analysis, which however met the required assumptions as discussed in the previous paragraph. To improve the study validity, we followed a mixed-methods approach, in which quantitative and qualitative findings support each other and we focused on participants with specific characteristics. Our participants' age-span was limited (18–30). However, the ages were normally distributed and reflect the age-span of gamers [135], the gender distribution reflects gamers' gender distribution [135], and GEFT scores are comparably similar to the general public across populations with varying demographics [99, 102, 160]. We acknowledge that teamwork and collaboration can be affected by other factors that we did not control for in this study, such as gender, social intelligence, and personality. While these factors might have contributed to how the teams interacted within the game, controlling for each of these factors would have resulted in a very complex study design. We anticipate that future work could address such limitation. Moreover, we acknowledge that one of the shortcomings of this work is that we conducted the study using one single custom-made multiplayer game. While the design of the *TeCP* game was inspired by different game design patterns and other popular cooperative games, is it not a representative of mainstream games. Further research should investigate how cognitive styles impact collaborative gameplay using different off-the-shelf collaborative games and games from other genres, improving the generalizability of our findings.

To achieve a high ecological validity, we performed the study in an internet/games café, which is a place designed for gaming sessions. The study participants used the available gaming apparatus (e.g., computers, mouse, keyboard, headphones), which supported *TeCP* and did not interfere with participants' experience. The study participants were all experienced gamers, who had played games with similar mechanics and were customers of the internet/games café. Hence, they were familiar with the study environment and the equipment, which helped them behave and act naturally.

7.2 Social Presence, Cultural Differences, and Skill Levels

We acknowledge that this work is limited and a number of extraneous variables including social presence of other players and differences in culture and skill levels between the players can potentially be an influencing factor on the results presented. We discuss each of these variables here and cite prior work that can help in understanding the effects of these variables.

Video games are commonly played in social settings with co-players and audiences. Prior research suggests that when a player is watched by an audience or another co-located person, the *presence* of others in the physical and virtual space might influence the gameplay experience. *Presence* is defined as a subjective phenomenon of being "there", the psychological sense of sharing of physical and virtual places and spaces with others [24, 119, 172]. Playing video games in open social settings, such as in a public internet/games café or through an online streaming platform (e.g., Twitch.tv[2]) with other players and spectators have the potential to influence how players interact and behave [80, 96, 105, 116, 125]. Kimble and Rezabek [105] studied the impact of an audience on a players' performance. The authors argue that "good players would do better and poor players would do worse under audience pressure". Lin and Sun [116] also investigated the relationship between players and *onlookers* in video game arcades. The authors suggest that the presence of onlookers and audiences can promote positive performance. Kappen et al. [96] studied the influence of different types of co-located audiences (no audience, silent audience, positive audience, and negative audience) and how each type of audiences influence the gameplay experience. The authors found that negative and positive audience influnced players the most by making them become more engaged in the video game. On the other hand, silent audiences caused players to be less engaged in gameplay.

While we understand that social presence of other co-located players and audiences may influence the gameplay experience and performance as suggested by these prior literature and we acknowledge that we did not control for such influence, we argue that conducting our user study in a internet/games café provided a highly ecological valid environment, an environment that our experienced players are familiar with and feel confidant in. We argue that since all our participants were experienced players and were familiar with the game type and the internet/games café, the presence of other co-located players and audiences had little to no negative impact on the players as suggested by Kimble and Rezabek [105] and Lin and Sun [116].

In regards to cultural differences, prior research suggests that culture orientation plays a small part of how people play and interact in social games [115, 142]. Prior work on cognitive styles shows that there is a cross-cultural variation in FD-I cognitive style and that people with different cultural backgrounds (e.g., individualist and collectivist cultures [111]) tend to move towards the one or the other dimension. In our study, all participants shared the same culture orientation, hence the impact of culture differences on our participants is considered to be minimal.

In regards to differences in skill levels, all participants were experienced players and were familiar with cooperative games similar to *TeCP*. We argue that skill differences between players had minimal influence on the gameplay experience and the results of the study.

Despite all of these different extraneous variables that were not controlled for in this study, our work adds to a growing body of research on collaborative gameplay in multiplayer games (e.g., [5, 6, 9, 10, 104, 114, 202, 203]) and creates a bridge connecting cognitive styles and collaborative gameplay. Our work sheds light on how cognitive styles influence collaborative gameplay and provides valuable insights and a deep understanding of how players' characteristics influence teamwork. While the findings of this study contribute valuable insights and suggest many implications for future design and research, they must be viewed within the study's limitations.

8 CONCLUSION

In multiplayer collaborative games, players need to continuously collaborate and coordinate their actions with their teammates to succeed. The present research investigates the effects of cognitive styles on collaborative gameplay and provides an understanding of how players' cognitive characteristics influence their teamwork. Through a mixed-methods, between-subjects study, we empirically investigated how FD-I cognitive style impacts gameplay behavior, concerning how team performance, cognitive workload, player experience, and communication differ between players and teams. The results show that teams that consist of two FD-style players had poor performance and increased mental workload, despite communicating verbally and using annotations. Additionally,

[2]https://www.twitch.tv

groups that had at least one FI-style player performed better. These results contribute to understanding cognitive styles and collaborative gameplay by providing empirical evidence and new insights on how players' information seeking, problem-solving, communication, and navigation approaches influence their behavior and strategy when playing a multiplayer collaborative game. These findings suggest that cognitive style should be one of the human factors considered when designing collaborative games.

9 ACKNOWLEDGMENTS

We thank SpiderNet Internet Café for providing their space and equipment, contributing to the ecological validity of the study. Lennart Nacke thanks the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery (RGPIN-2018-06576, Developing and Analyzing Immersive Game Technologies and Components for Motivation, Wellbeing, and Guidance), NSERC CREATE SWaGUR, the Canada Foundation for Innovation (CFI, 35819, John R. Evans Leaders Fund), the Canadian Institutes of Health Research (CIHR) under the Active and Assisted Living (AAL) Programme, and Mitacs for funding his research team. This material is based upon work supported by the National Science Foundation under Grant Nos. IIS-1651532 and IIS-1619273.

REFERENCES

[1] Ernest Adams and Joris Dormans. 2012. *Game Mechanics: Advanced Game Design* (1st ed.). New Riders Publishing, Thousand Oaks, CA, USA.

[2] David S. Alberts, John J. Garstka, Richard E. Hayes, and David A. Signori. 2001. *Understanding Information age Warfare*. Technical Report. DTIC Document.

[3] Sultan A. Alharthi, William A. Hamilton, Igor Dolgov, and Z O. Toups. 2018. Mapping in the Wild: Toward Designing to Train Search & Rescue Planning. In *Companion of the 2018 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW '18)*. Association for Computing Machinery, New York, NY, USA, 137–140. https://doi.org/10.1145/3272973.3274039

[4] Sultan A. Alharthi, Nick LaLone, Ahmed S. Khalaf, Ruth C. Torres, Lennart E. Nacke, Igor Dolgov, and Z O. Toups. 2018. Practical Insights into the Design of Future Disaster Response Training Simulations. In *Proc. 15th ISCRAM Conference*. 818–830.

[5] Sultan A. Alharthi, George E. Raptis, Christina Katsini, Igor Dolgov, Lennart E. Nacke, and Z O. Toups. 2018. Toward Understanding the Effects of Cognitive Styles on Collaboration in Multiplayer Games. In *Companion of the 2018 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW '18)*. ACM, New York, NY, USA, 169–172. https://doi.org/10.1145/3272973.3274047

[6] Sultan A. Alharthi, George E. Raptis, Christina Katsini, Igor Dolgov, Lennart E. Nacke, and Zachary O. Toups. 2019. Do Cognitive Styles Influence Collective Sensemaking in Distributed Multiplayer Games?. In *Proceedings of the 2019 Collective Intelligence Conference (CI '19)*. Association for Computing Machinery, New York, NY, USA.

[7] Sultan A. Alharthi, Hitesh Nidhi Sharma, Sachin Sunka, Igor Dolgov, and Z O. Toups. 2018. Designing Future Disaster Response Team Wearables from a Grounding in Practice. In *Proceedings of Technology, Mind, and Society (TechMindSociety '18)*. ACM, New York, NY, USA. https://doi.org/10.1145/3183654.3183662

[8] Sultan A. Alharthi, Ruth C. Torres, Ahmed S. Khalaf, and Z O. Toups. 2017. The Maze: Enabling Collaborative Planning in Games Through Annotation Interfaces. In *Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play*. Association for Computing Machinery, New York, NY, USA, 615–620. https://doi.org/10.1145/3130859.3130864

[9] Sultan A. Alharthi, Ruth C. Torres, Ahmed S. Khalaf, Z O. Toups, Igor Dolgov, and Lennart E. Nacke. 2018. Investigating the Impact of Annotation Interfaces on Player Performance in Distributed Multiplayer Games. In *Proc. SIGCHI Conf. Human Factors in Comp. Sys. (CHI '18)*. ACM, 314:1–314:13.

[10] Essa Alhazmi, Sameera Horawalavithana, John Skvoretz, Jeremy Blackburn, and Adriana Iamnitchi. 2017. An Empirical Study on Team Formation in Online Games. In *Proceedings of the 2017 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining 2017 (ASONAM '17)*. ACM, New York, NY, USA, 431–438. https://doi.org/10.1145/3110025.3110094

[11] Christopher W. Allinson and John Hayes. 1996. The Cognitive Style Index: A Measure of Intuition-Analysis For Organizational Research. *Journal of Management Studies* 33, 1 (1996), 119–135. https://doi.org/10.1111/j.1467-6486.1996.tb00801.x arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-6486.1996.tb00801.x

[12] Arif Altun and Mehtap Cakan. 2006. Undergraduate Students' Academic Achievement, Field Dependent/Independent Cognitive Styles and Attitude toward Computers. *Educational Technology and Society* 9, 1 (2006), 289–297.

[13] Charoula Angeli and Nicos Valanides. 2013. Using Educational Data Mining Methods to Assess Field-Dependent and Field-Independent Learners' Complex Problem Solving. *Educational Technology Research and Development* 61, 3 (April 2013), 521–548. https://doi.org/10.1007/s11423-013-9298-1

[14] Charoula Angeli, Nicos Valanides, and Paul Kirschner. 2009. Field Dependence-Independence and Instructional-design Effects on Learners' Performance with a Computer-Modeling Tool. *Computers in Human Behavior* 25, 6 (Nov 2009), 1355–1366. https://doi.org/10.1016/j.chb.2009.05.010

[15] Steven J. Armstrong, Eva Cools, and Eugene Sadler-Smith. 2012. Role of Cognitive Styles in Business and Management: Reviewing 40 Years of Research. *International Journal of Management Reviews* 14, 3 (Sep 2012), 238–262. https://doi.org/10.1111/j.1468-2370.2011.00315.x

[16] Chris Baber, James Cross, Paul Smith, and Dengel Robinson. 2007. *Supporting Implicit Coordination Between Distributed Teams in Disaster Management.* Springer Berlin Heidelberg, Berlin, Heidelberg, 39–50. https://doi.org/10.1007/978-3-540-75668-2_5

[17] Mehmet Bahar and Mike H. Hansell. 2000. The Relationship Between Some Psychological Factors and their Effect on the Performance of Grid Questions and Word Association Tests. *Educational Psychology* 20, 3 (Sep 2000), 349–364. https://doi.org/10.1080/713663739

[18] David P. Baker and Eduardo Salas. 1992. Principles for Measuring Teamwork Skills. *Human Factors* 34, 4 (1992), 469–475. https://doi.org/10.1177/001872089203400408 arXiv:https://doi.org/10.1177/001872089203400408

[19] Staffan Björk, Sus Lundgren, and Jussi Holopainen. 2003. Game Design Patterns. In *Level Up - Proceedings of Digital Games Research Conference 2003.*

[20] Olesya Blazhenkova and Maria Kozhevnikov. 2008. The New Object-Spatial-Verbal Cognitive Style Model: Theory and Measurement. *Applied Cognitive Psychology* 23, 5 (2008), 638–663. https://doi.org/10.1002/acp.1473 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/acp.1473

[21] Maddalena Boccia, Francesca Vecchione, Laura Piccardi, and Cecilia Guariglia. 2017. Effect of Cognitive Style on Learning and Retrieval of Navigational Environments. *Frontiers in Pharmacology* 8 (July 2017). https://doi.org/10.3389/fphar.2017.00496

[22] Frederic J. Boersma. 1968. Test-Retest Reliability of the Cf-1 Hidden Figures Test1. *Educational and Psychological Measurement* 28, 2 (July 1968), 555–559. https://doi.org/10.1177/001316446802800244

[23] Nataliya V. Bogacheva. 2016. Cognitive Styles Specifics of Adult Computer Gamers. *Annual Review of Cybertherapy and Telemedicine* (2016), 84.

[24] Stéphane Bouchard, Jeanne Talbot, André-Anne Ledoux, Jennifer Phillips, Matteo Cantamasse, and Geneviéve Robillard. 2009. The meaning of being there is related to a specific activation in the brain located in the parahypocampus. *Proceedings of Presence* (2009).

[25] Virginia Braun and Victoria Clarke. 2006. Using Thematic Analysis in Psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[26] William Bridges. 2000. *The Character of Organizations: Using Personality Type in Organization Development.* Nicholas Brealey Publishing.

[27] Barry Brown and Marek Bell. 2004. CSCW at Play: 'There' As a Collaborative Virtual Environment. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work (CSCW '04).* ACM, New York, NY, USA, 350–359. https://doi.org/10.1145/1031607.1031666

[28] Brian Cameron and Francis Dwyer. 2005. The Effect of Online Gaming, Cognition and Feedback Type in Facilitating Delayed Achievement of Different Learning Objectives. *Journal of Interactive Learning Research* 16, 3 (July 2005), 243–258. https://www.learntechlib.org/p/5896

[29] Justin V Cavallo, John G Holmes, Gráinne M Fitzsimons, Sandra L Murray, and Joanne V Wood. 2012. Managing Motivational Conflict: How Self-Esteem and Executive Resources Influence Self-Regulatory Responses to Risk. *Journal of Personality and Social Psychology* 103, 3 (2012), 430.

[30] Jared E. Cechanowicz, Carl Gutwin, Scott Bateman, Regan Mandryk, and Ian Stavness. 2014. Improving Player Balancing in Racing Games. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14).* ACM, New York, NY, USA, 47–56. https://doi.org/10.1145/2658537.2658701

[31] Gerry Chan, Ali Arya, and Anthony Whitehead. 2018. Keeping Players Engaged in Exergames: A Personality Matchmaking Approach. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA '18).* ACM, New York, NY, USA, Article LBW064, 6 pages. https://doi.org/10.1145/3170427.3188455

[32] Ben Chang, Sherry Y. Chen, and Sin-Ni Jhan. 2015. The Influences of an Interactive Group-based Videogame: Cognitive Styles vs. Prior Ability. *Computers & Education* 88 (2015), 399 – 407. https://doi.org/10.1016/j.compedu.2015.08.006

[33] Kui Chen, Mitsuhiro Kamezaki, Takahiro Katano, Junjie Yang, Tatsuzo Ishida, Masatoshi Seki, Ken Ichiryu, and Shigeki Sugano. 2016. Fundamental Development of a Virtual Reality Simulator for Four-Arm Disaster Rescue

Robot OCTOPUS. In *2016 IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*. 721–726. https://doi.org/10.1109/AIM.2016.7576853

[34] Sherry Y. Chen and Xiaohui Liu. 2008. An Integrated Approach for Modeling Learning Patterns of Students in Web-Based Instruction: A Cognitive Style Perspective. *ACM Transactions on Computer-Human Interaction* 15, 1, Article 1 (May 2008), 28 pages. https://doi.org/10.1145/1352782.1352783

[35] Victor Cheung, Y.-L. Betty Chang, and Stacey D. Scott. 2012. Communication Channels and Awareness Cues in Collocated Collaborative Time-critical Gaming. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work (CSCW '12)*. ACM, New York, NY, USA, 569–578. https://doi.org/10.1145/2145204.2145291

[36] Huey-Wen Chou. 2001. Influences of Cognitive Style and Training Method on Training Effectiveness. *Computers & Education* 37, 1 (2001), 11–25. https://doi.org/10.1016/S0360-1315(01)00028-8

[37] Herbert H. Clark. 1996. *Using Language*. Cambridge University Press.

[38] Susan W. Coates. 1972. *Preschool Embedded Figures Test: PEFT*. Consulting Psychologists Press, Palo Alto, CA, USA.

[39] Edward E. Cureton. 1957. The Upper and Lower Twenty-Seven per Cent Rule. *Psychometrika* 22, 3 (Sep 1957), 293–296. https://doi.org/10.1007/BF02289130

[40] Katherine Deibel. 2005. Team Formation Methods for Increasing Interaction During In-class Group Work. In *Proceedings of the 10th Annual SIGCSE Conference on Innovation and Technology in Computer Science Education (ITiCSE '05)*. ACM, New York, NY, USA, 291–295. https://doi.org/10.1145/1067445.1067525

[41] Jack Demick and Seymour Wapner. 1991. Field Dependence-Independence in Adult Development and Aging. (1991).

[42] Paul Dourish and Victoria Bellotti. 1992. Awareness and Coordination in Shared Workspaces. In *Proceedings of the 1992 ACM Conference on Computer-supported Cooperative Work (CSCW '92)*. ACM, New York, NY, USA, 107–114. https://doi.org/10.1145/143457.143468

[43] Aude Dufresne and Sylvie Turcotte. 1997. Cognitive Style and Its Implications for Navigation Strategies.

[44] Francis M. Dwyer and David M. Moore. 1992. Effect of Color Coding on Visually and Verbally Oriented Tests with Students of Different Field Dependence Levels. *Journal of Educational Technology Systems* 20, 4 (1992), 311–320. https://doi.org/10.2190/T0EY-KF0H-0RTV-X5DG arXiv:https://doi.org/10.2190/T0EY-KF0H-0RTV-X5DG

[45] Joshua A. Eaton, Matthew-Donald D. Sangster, Molly Renaud, and Wayne D. Mendonca, David J.and Gray. 2017. Carrying the Team: The Importance of One Player's Survival for Team Success in League of Legends. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 61, 1 (2017), 272–276. https://doi.org/10.1177/1541931213601550 arXiv:https://doi.org/10.1177/1541931213601550

[46] Simon Egenfeldt-Nielsen, Jonas Heide Smith, and Susana Pajares Tosca. 2012. *Understanding Video Games: The Essential Introduction* (2nd ed.). Routledge, USA.

[47] Mica R. Endsley. 1995. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors* 37, 1 (1995).

[48] Mica R. Endsley. 2000. Theoretical Underpinnings of Situation Awareness: A Critical Review. In *Situation Awareness Analysis and Measurement*, Endsley. Mica R. and Daniel J. Garland (Eds.). Lawrence Erlbaum Associates, Mahwah, NJ, USA, 3–6.

[49] Epic Games. 2018. *Fortnite Battle Royale*. Game [Switch]. (12 June 2018). Epic Games, Cary, North Carolina, USA.

[50] Omid Fakourfar, Kevin Ta, Richard Tang, Scott Bateman, and Anthony Tang. 2016. Stabilized Annotations for Mobile Remote Assistance. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 1548–1560. https://doi.org/10.1145/2858036.2858171

[51] David J. Falcone. 1985. Laterality and Field Dependence. *Perceptual and Motor Skills* 61, 2 (Oct. 1985), 651–657. https://doi.org/10.2466/pms.1985.61.2.651

[52] Cristina Farmaki, Vangelis Sakkalis, Frank Loesche, and Efi A. Nisiforou. 2019. Assessing Field Dependence-Independence Cognitive Abilities Through EEG-Based Bistable Perception Processing. *Frontiers in Human Neuroscience* 13 (Oct. 2019). https://doi.org/10.3389/fnhum.2019.00345

[53] Henry D. Fernandez B., Koji Mikami, and Kunio Kondo. 2017. Adaptable Game Experience Based on Player's Performance and EEG. In *2017 Nicograph International (NicoInt)*. 1–8. https://doi.org/10.1109/NICOInt.2017.11

[54] Gordon Fitch. 1970. Effects of Self-Esteem, Perceived Performance, and Choice on Causal Attributions. *Journal of personality and social psychology* 16, 2 (1970), 311.

[55] Nigel Ford. 2000. Cognitive styles and virtual environments. *Journal of the Association for Information Science and Technology* 51, 6 (2000), 543.

[56] Nigel Ford and Sherry Y Chen. 2001. Matching/Mismatching Revisited: An Empirical Study of Learning and Teaching Styles. *British Journal of Educational Technology* 32, 1 (2001), 5–22. https://doi.org/10.1111/1467-8535.00173

[57] Bernard M Frank and J Kent Davis. 1982. Effect of Field-Independence Match or Mismatch on a Communication Task. *Journal of Educational Psychology* 74, 1 (1982), 23. https://doi.org/10.1037/0022-0663.74.1.23

[58] Marlena R. Fraune, Ahmed S. Khalaf, Mahlet Zemedie, Poom Pianpak, Zahra NaminiMianji, Sultan A. Alharthi, Igor Dolgov, Bill Hamilton, Son Tran, and Z O. Toups. 2021. Developing Future Wearable Interfaces for Human-Drone Teams through a Virtual Drone Search Game. *International Journal of Human-Computer Studies* 147 (2021), 102573.

https://doi.org/10.1016/j.ijhcs.2020.102573
[59] Guo Freeman and Donghee Yvette Wohn. 2017. Understanding eSports Team Formation and Coordination. *Computer Supported Cooperative Work (CSCW)* (27 Oct 2017). https://doi.org/10.1007/s10606-017-9299-4
[60] Delane K Garlinger and Bernard M Frank. 1986. Teacher-Student Cognitive Style and Academic Achievement: A Review and Mini-Meta-Analysis. *The Journal of Classroom Interaction* (1986), 2–8.
[61] Christine Garrick. 1978. Field Dependence and Hemispheric Specialization. *Perceptual and Motor Skills* 47, 2 (Dec. 1978), 631–639. https://doi.org/10.2466/pms.1978.47.2.631
[62] Dedre Gentner and Albert L. Stevens. 1983. *Mental Models.* Lawrence Earlbaum Associates, Hillsdale, NJ, USA.
[63] Kathrin Maria Gerling, Matthew Miller, Regan L. Mandryk, Max Valentin Birk, and Jan David Smeddinck. 2014. Effects of Balancing for Physical Abilities on Player Performance, Experience and Self-esteem in Exergames. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14).* ACM, New York, NY, USA, 2201–2210. https://doi.org/10.1145/2556288.2556963
[64] Alan Gevins and Michael E. Smith. 2000. Neurophysiological Measures of Working Memory and Individual Differences in Cognitive Ability and Cognitive Style. *Cerebral Cortex* 10, 9 (Sept. 2000), 829–839. https://doi.org/10.1093/cercor/10.9.829
[65] Alan Glass and Richard J. Riding. 1999. EEG Differences and Cognitive Style. *Biological Psychology* 51, 1 (Oct. 1999), 23–41. https://doi.org/10.1016/s0301-0511(99)00014-9
[66] Joseph Glicksohn, Yulia Naftuliev, and Hilla Golan-Smooha. 2007. Extraversion, Psychoticism, Sensation Seeking and Field Dependence–Independence: Will the True Relationship Please Reveal Itself? *Personality and Individual Differences* 42, 7 (2007), 1175 – 1185. https://doi.org/10.1016/j.paid.2006.09.025
[67] Tamar Globerson. 1989. . Ablex Publishing, Westport, CT, USA, Chapter What is the Relationship between Cognitive Style and Cognitive Development?, 71–85.
[68] Patrick E. Goode, Phil H. Goddard, and Juan Pascual-Leone. 2002. Event-related Potentials Index Cognitive Style Differences during a Serial-Order Recall Task. *International Journal of Psychophysiology* 43, 2 (Feb. 2002), 123–140. https://doi.org/10.1016/s0167-8760(01)00158-1
[69] Harrison G. Gough and Robert M. Olton. 1972. Field Independence as Related to Nonverbal Measures of Perceptual Performance and Cognitive Ability. *Journal of Consulting and Clinical Psychology* 38, 3 (1972), 338–342. https://doi.org/10.1037/h0032889
[70] Palash Goyal, Anna Sapienza, and Emilio Ferrara. 2018. Recommending Teammates with Deep Neural Networks. In *Proceedings of the 29th on Hypertext and Social Media (HT '18).* ACM, New York, NY, USA, 57–61. https://doi.org/10.1145/3209542.3209569
[71] C. Shawn Green and Aaron R. Seitz. 2015. The Impacts of Video Games on Cognition (and How the Government Can Guide the Industry). *Policy Insights from the Behavioral and Brain Sciences* 2, 1 (Oct. 2015), 101–110. https://doi.org/10.1177/2372732215601121
[72] C. Shawn Green, Michael A. Sugarman, Katherine Medford, Elizabeth Klobusicky, and Daphne Bavelier. 2012. The Effect of Action Video Game Experience on Task-Switching. *Computers in Human Behavior* 28, 3 (May 2012), 984–994. https://doi.org/10.1016/j.chb.2011.12.020
[73] Andreas Gregoriades and Alistair Sutcliffe. 2008. Workload Prediction for Improved Design and Reliability of Complex Systems. *Reliability Engineering & System Safety* 93, 4 (2008), 530–549. https://doi.org/10.1016/j.ress.2007.02.001
[74] Leopold W. Gruenfeld and Thung-Rung Lin. 1984. Social Behavior of Field Independents and Dependents in an Organic Group. *Human Relations* 37, 9 (Sept. 1984), 721–741. https://doi.org/10.1177/001872678403700902
[75] Joy Paul Guilford. 1980. Cognitive Styles: What Are They? *Educational and Psychological Measurement* 40, 3 (Oct. 1980), 715–735. https://doi.org/10.1177/001316448004000315
[76] Carl Gutwin and Saul Greenberg. 2002. A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Computer Supported Cooperative Work (CSCW)* 11, 3 (Sep 2002), 411–446. https://doi.org/10.1023/A:1021271517844
[77] Carl Gutwin and Saul Greenberg. 2004. The Importance of Awareness for Team Cognition in Distributed Collaboration. In *Team Cognition: Understanding the Factors that Drive Process and Performance* (1st ed.), Eduardo Salas and Stephen M. Fiore (Eds.). American Psychological Association, Washington, DC, USA, Chapter 9, 177–201.
[78] Carl Gutwin, Saul Greenberg, and Mark Roseman. 1996. *Workspace Awareness in Real-Time Distributed Groupware: Framework, Widgets, and Evaluation.* Springer London, London, 281–298. https://doi.org/10.1007/978-1-4471-3588-3_18
[79] William Hamilton, Andruid Kerne, and Tom Robbins. 2012. High-performance Pen + Touch Modality Interactions: A Real-time Strategy Game eSports Context. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology (UIST '12).* ACM, New York, NY, USA, 309–318. https://doi.org/10.1145/2380116.2380156
[80] William A. Hamilton, Oliver Garretson, and Andruid Kerne. 2014. Streaming on Twitch: Fostering Participatory Communities of Play Within Live Mixed Media. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14).* ACM, New York, NY, USA, 1315–1324. https://doi.org/10.1145/2556288.2557048

[81] Xin Hao, Kangcheng Wang, Wenfu Li, Wenjing Yang, Dongtao Wei, Jiang Qiu, and Qinglin Zhang. 2013. Individual Differences in Brain Structure and Resting Brain Function Underlie Cognitive Styles: Evidence from the Embedded Figures Test. *PLoS ONE* 8, 12 (Dec. 2013), e78089. https://doi.org/10.1371/journal.pone.0078089

[82] Sandra G. Hart. 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, 9 (2006), 904–908. https://doi.org/10.1177/154193120605000909

[83] Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Human Mental Workload*, Peter A. Hancock and Najmedin Meshkati (Eds.). 239–250.

[84] David Hecht and Miriam Reiner. 2007. Field Dependency and the Sense of Object-Presence in Haptic Virtual Environments. *CyberPsychology & Behavior* 10, 2 (April 2007), 243–251. https://doi.org/10.1089/cpb.2006.9962

[85] James Hollan, Edwin Hutchins, and David Kirsh. 2000. Distributed Cognition: Toward a New Foundation for Human-computer Interaction Research. *ACM Trans. Comput.-Hum. Interact.* 7, 2 (June 2000), 174–196. https://doi.org/10.1145/353485.353487

[86] Jussi Holopainen. 2011. *Foundations of Gameplay.* Ph.D. Dissertation. Blekinge Institute of Technology.

[87] Jon-Chao Hong, Ming-Yueh Hwang, Ker-Ping Tam, Yi-Hsuan Lai, and Li-Chun Liu. 2012. Effects of Cognitive Style on Digital Jigsaw Puzzle Performance: A GridWare Analysis. *Computers in Human Behavior* 28, 3 (2012), 920 – 928. https://doi.org/10.1016/j.chb.2011.12.012

[88] Virginia M. Horak. 1990. Students' Cognitive Styles and Their Use of Problem-Solving Heuristics and Metacognitive Processes. (1990).

[89] Robin Hunicke, Marc LeBlanc, and Robert Zubek. 2004. MDA: A Formal Approach to Game Design and Game Research. In *Proceedings of the AAAI Workshop on Challenges in Game AI*, Vol. 4. 1722.

[90] Dan Jensen, John Feland, Martin Bowe, and Brian Self. 2000. A 6-Hats based Team Formation Strategy: Development and Comparison with an MBTI based Approach. In *Proceedings of the ASEE Annual Conference*. 419–427.

[91] Colby Johanson, Carl Gutwin, and Regan L. Mandryk. 2017. The Effects of Navigation Assistance on Spatial Learning and Performance in a 3D Game. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '17)*. ACM, New York, NY, USA, 341–353. https://doi.org/10.1145/3116595.3116602

[92] David H. Jonassen and Philip Henning. 1996. Mental Models: Knowledge in the Head and Knowledge in the World. In *ICLS '96: Proceedings of the 1996 International Conference on Learning Sciences*. International Society of the Learning Sciences, 433–438.

[93] Kristine Jørgensen. 2013. *Gameworld Interfaces.* MIT Press, Cambridge, MA, USA.

[94] Timothy A. Judge, Chad A. Higgins, Carl J. Thoresen, and Murray R. Barrick. 1999. THE BIG FIVE PERSONALITY TRAITS, GENERAL MENTAL ABILITY, AND CAREER SUCCESS ACROSS THE LIFE SPAN. *Personnel Psychology* 52, 3 (1999), 621–652. https://doi.org/10.1111/j.1744-6570.1999.tb00174.x arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1744-6570.1999.tb00174.x

[95] Hye-Ryun Kang, Hee-Dong Yang, and Chris Rowley. 2006. Factors in Team Effectiveness: Cognitive and Demographic Similarities of Software Development Team Members. *Human Relations* 59, 12 (2006), 1681–1710. https://doi.org/10.1177/0018726706072891 arXiv:https://doi.org/10.1177/0018726706072891

[96] Dennis L. Kappen, Pejman Mirza-Babaei, Jens Johannsmeier, Daniel Buckstein, James Robb, and Lennart E. Nacke. 2014. Engaged by Boos and Cheers: The Effect of Co-located Game Audiences on Social Player Experience. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14)*. ACM, New York, NY, USA, 151–160. https://doi.org/10.1145/2658537.2658687

[97] Stephen A. Karp and Norma L. Konstadt. 1971. Children's Embedded Figures Test. In *A Manual for the Embedded Figures Test*, E. Raskin S. A. Karp H. A. Witkin, K. Oltman (Ed.). Consulting Psychologists Press, Palo Alto, CA, 21–26.

[98] Christina Katsini, Christos Fidas, George E. Raptis, Marios Belk, George Samaras, and Nikolaos Avouris. 2018. Eye Gaze-driven Prediction of Cognitive Differences During Graphical Password Composition. In *23rd International Conference on Intelligent User Interfaces (IUI '18)*. ACM, New York, NY, USA, 147–152. https://doi.org/10.1145/3172944.3172996

[99] Christina Katsini, Christos Fidas, George E. Raptis, Marios Belk, George Samaras, and Nikolaos Avouris. 2018. Influences of Human Cognition and Visual Behavior on Password Strength During Picture Password Composition. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 87, 14 pages. https://doi.org/10.1145/3173574.3173661

[100] Marc D. Kepner and Edith D. Neimark. 1984. Test–Retest Reliability and Differential Patterns of Score Change on the Group Embedded Figures Test. *Journal of Personality and Social Psychology* 46, 6 (June 1984), 1405–1413. https://doi.org/10.1037/0022-3514.46.6.1405

[101] Ahmed S. Khalaf, Poom Pianpak, Sultan A. Alharthi, Zahra NaminiMianji, Ruth Torres, Son Tran, Igor Dolgov, and Z O. Toups. 2018. An Architecture for Simulating Drones in Mixed Reality Games to Explore Future Search and Rescue Scenarios. In *ISCRAM 2018 Conference Proceedings – 15th International Conference on Information Systems for Crisis Response and Management*, Kees Boersma and Brian Tomaszeski (Eds.). 971–982.

[102] Mohammad Khatib and Rasoul Mohammad Hosseinpur. 2011. On the Validity of the Group Embedded Figure Test (GEFT). *Journal of Language Teaching and Research* 2, 3 (May 2011). https://doi.org/10.4304/jltr.2.3.640-648

[103] Kyung-Sun Kim. 2001. Implications of User Characteristics in Information Seeking on the World Wide Web. *International Journal of Human–Computer Interaction* 13, 3 (2001), 323–340.

[104] Young Ji Kim, David Engel, Anita Williams Woolley, Jeffrey Yu-Ting Lin, Naomi McArthur, and Thomas W. Malone. 2017. What Makes a Strong Team?: Using Collective Intelligence to Predict Team Performance in League of Legends. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW '17)*. ACM, New York, NY, USA, 2316–2329. https://doi.org/10.1145/2998181.2998185

[105] Charles E. Kimble and Jeffery S. Rezabek. 1992. Playing Games Before An Audience: Social Facilitation or Choking. *Social Behavior and Personality: an international journal* 20, 2 (1992).

[106] Michael Kirton. 1976. Adaptors and Innovators: A Description and Measure. *Journal of Applied Psychology* 61, 5 (1976), 622–629. https://doi.org/10.1037/0021-9010.61.5.622

[107] Nathan Kogan. 1991. Field Dependence-Independence from Early Childhood through Adolescence: Personality and Socialization Aspects. *Field Dependence-Independence: Cognitive Style Across the Life Span* (1991), 177–207.

[108] Maria Kozhevnikov. 2007. Cognitive styles in the context of modern psychology: Toward an integrated framework of cognitive style. *Psychological Bulletin* 133, 3 (2007), 464.

[109] Maria Kozhevnikov, Stephen Kosslyn, and Jennifer Shephard. 2005. Spatial versus Object Visualizers: A New Characterization of Visual Cognitive Style. *Memory & Cognition* 33, 4 (June 2005), 710–726. https://doi.org/10.3758/bf03195337

[110] Oskar Ku, Chi-Chen Hou, and Sherry Y. Chen. 2016. Incorporating Customization and Personalization into Game-based Learning: A Cognitive Style Perspective. *Computers in Human Behavior* 65 (2016), 359–368. https://doi.org/10.1016/j.chb.2016.08.040

[111] Ulrich Kühnen, Bettina Hannover, Ute Roeder, Ashiq Ali Shah, Benjamin Schubert, Arnold Upmeyer, and Saliza Zakaria. 2001. Cross-Cultural Variations in Identifying Embedded Figures. *Journal of Cross-Cultural Psychology* 32, 3 (May 2001), 366–372. https://doi.org/10.1177/0022022101032003007

[112] Fan-Ray Kuo, Gwo-Jen Hwang, Szu-Chuang Chen, and Sherry Y Chen. 2012. A Cognitive Apprenticeship Approach to Facilitating Web-based Collaborative Problem Solving. *Journal of Educational Technology & Society* 15, 4 (2012).

[113] Maria Kyprianidou, Stavros Demetriadis, Thrasyvoulos Tsiatsos, and Andreas Pombortsis. 2012. Group Formation based on Learning Styles: Can it Improve Students' Teamwork? *Educational Technology Research and Development* 60, 1 (01 Feb 2012), 83–110. https://doi.org/10.1007/s11423-011-9215-4

[114] Alex Leavitt, Brian C. Keegan, and Joshua Clark. 2016. Ping to Win?: Non-Verbal Communication and Team Performance in Competitive Online Multiplayer Games. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 4337–4350. https://doi.org/10.1145/2858036.2858132

[115] Yu-Hao Lee and Donghee Yvette Wohn. 2012. Are There Cultural Differences in How We Play? Examining Cultural Effects on Playing Social Network Games. *Computers in Human Behavior* 28, 4 (2012), 1307–1314. https://doi.org/10.1016/j.chb.2012.02.014

[116] Holin Lin and Chuen-Tsai Sun. 2011. The Role of Onlookers in Arcade Gaming: Frame Analysis of Public Behaviours. *Convergence* 17, 2 (2011), 125–137. https://doi.org/10.1177/1354856510397111 arXiv:https://doi.org/10.1177/1354856510397111

[117] Min Liu and Michael W. Reed. 1994. The Relationship Between the Learning Strategies and Learning Styles in a Hypermedia Environment. *Computers in Human Behavior* 10, 4 (1994), 419–434. https://doi.org/10.1016/0747-5632(94)90038-8

[118] Jia-Jiunn Lo and Yun-Jay Wang. 2012. Development of an Adaptive EC Website With Online Identified Cognitive Styles of Anonymous Customers. *International Journal of Human-Computer Interaction (IJHCI)* 28, 9 (Sep 2012), 560–575. https://doi.org/10.1080/10447318.2011.629952

[119] Patrick R. Lowenthal. 2010. Social presence. In *Social Computing: Concepts, Methodologies, Tools, and Applications*. IGI Global, 129–136.

[120] Chin-hsieh Lu, Jon-Chou Hong, and Pei-hsiu Huang. 2007. The Effects of Individual Characteristics on Children's Problem Solving Performances in the Context of Game-based Learning. *Redesigning Pedagogy: Culture, Knowledge and Understanding. National Institute of Education, Singapore* (2007).

[121] Ting-Yun Lu. 2014. *Effects of Collaborative Reading Annotation System with Reading Navigation Map on Enhancing Text Structure Comprehension.* Master's thesis. National Taiwan Normal University.

[122] Jean MacMillan, Elliot E. Entin, and Daniel Serfaty. 2004. Communication Overhead: The Hidden Cost of Team Cognition. In *Team Cognition: Understanding the Factors that Drive Process and Performance*, Eduardo Salas and Stephen M. Fiore (Eds.). American Psychological Association, Washington, DC, USA, 61–82.

[123] Freddy Mampadi, Sherry Y. Chen, Gheorghita Ghinea, and Ming-Puu Chen. 2011. Design of Adaptive Hypermedia Learning Systems: A Cognitive Style Approach. *Computers & Education* 56, 4 (May 2011), 1003–1011. https://doi.org/

10.1016/j.compedu.2010.11.018
[124] John E. Mathieu, Tonia S. Heffner, Gerald F. Goodwin, Eduardo Salas, and Janis A. Cannon-Bowers. 2000. The Influence of Shared Mental Models on Team Process and Performance. (2000), 273–283 pages. https://doi.org/10.1037/0021-9010.85.2.273
[125] Bernhard Maurer, Ilhan Aslan, Martin Wuchse, Katja Neureiter, and Manfred Tscheligi. 2015. Gaze-Based Onlooker Integration: Exploring the In-Between of Active Player and Passive Spectator in Co-Located Gaming. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '15)*. ACM, New York, NY, USA, 163–173. https://doi.org/10.1145/2793107.2793126
[126] Franco Mawad, Marcela Trías, Ana Giménez, Alejandro Maiche, and Gastón Ares. 2015. Influence of Cognitive Style on Information Processing and Selection of Yogurt Labels: Insights from an Eye-Tracking Study. *Food Research International* 74 (Aug 2015), 1–9. https://doi.org/10.1016/j.foodres.2015.04.023
[127] Rudy McDaniel and Robert Kenny. 2013. Evaluating the Relationship Between Cognitive Style and Pre-Service Teachers' Preconceived Notions About Adopting Console Video Games for Use in Future Classrooms. *International Journal of Game-Based Learning* 3, 2 (April 2013), 55–76. https://doi.org/10.4018/ijgbl.2013040104
[128] J. Jeffries McWhirter and Robert E.C. Frey. 1987. Group Leader and Member Characteristics and Attraction To Initial and Final Group Sessions and To the Group and Group Leader. *Small Group Behavior* 18, 4 (Nov. 1987), 533–547. https://doi.org/10.1177/104649648701800407
[129] Samuel Messick. 1976. Personality Consistencies in Cognition and Creativity. *Individuality in Learning* 4 (1976), 22.
[130] Snejina Michailova and Elena Sidorova. 2011. From Group-based Work to Organisational Learning: The Role of Communication Forms and Knowledge Sharing. *Knowledge Management Research & Practice* 9, 1 (2011), 73–83. https://doi.org/10.1057/kmrp.2011.4 arXiv:https://doi.org/10.1057/kmrp.2011.4
[131] Alan Miller. 1987. Cognitive Styles: An Integrated Model. *Educational Psychology* 7, 4 (Jan. 1987), 251–268. https://doi.org/10.1080/0144341870070401
[132] William F. Moroney, David W. Biers, F. Thomas Eggemeier, and Jennifer A. Mitchell. 1992. A comparison of two scoring procedures with the NASA Task Load Index in a simulated flight task. In *Proceedings of the IEEE 1992 National Aerospace and Electronics Conference (NAECON 1992)*. IEEE, 734–740. https://doi.org/10.1109/NAECON.1992.220513
[133] Fernando Felix do Nascimento Junior, Allan Sales da Costa Melo, Igor Barbosa da Costa, and Leandro Balby Marinho. 2017. Profiling Successful Team Behaviors in League of Legends. In *Proceedings of the 23rd Brazillian Symposium on Multimedia and the Web (WebMedia '17)*. ACM, New York, NY, USA, 261–268. https://doi.org/10.1145/3126858.3126886
[134] Julia Neidhardt, Yun Huang, and Noshir Contractor. 2015. Team vs. Team: Success Factors in a Multiplayer Online Battle Arena Game. *Academy of Management Proceedings* 2015, 1 (2015), 18725. https://doi.org/10.5465/ambpp.2015.18725abstract arXiv:https://doi.org/10.5465/ambpp.2015.18725abstract
[135] Newzoo. 2017. *Gamer Consumer Insights*. Technical Report.
[136] Efi A. Nisiforou. 2015. Examining the Association Between Users Creative Thinking and Field Dependence-Independence Cognitive Style Through Eye Movement Components. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition (C&C '15)*. ACM, New York, NY, USA, 205–208. https://doi.org/10.1145/2757226.2764556
[137] Czeslaw S. Nosal. 1990. Psychological Models of Mind. *PWN, Warsaw* (1990).
[138] Kieron P. O'Connor and J.C. Shaw. 1978. Field Dependence, Laterality and the EEG. *Biological Psychology* 6, 2 (March 1978), 93–109. https://doi.org/10.1016/0301-0511(78)90049-2
[139] Philip K. Oltman. 1968. A Portable Rod-and-Frame Apparatus. *Perceptual and Motor Skills* 26, 2 (1968), 503–506.
[140] Philip K. Oltman, Evelyn Raskin, and Herman A. Witkin. 1971. *Group Embedded Figures Test*. Consulting Psychologists Press Palo Alto, CA.
[141] Philip K. Oltman, Charmoin Semple, and Leonide Goldstein. 1979. Cognitive Style and Interhemispheric Differentiation in the EEG. *Neuropsychologia* 17, 6 (Jan. 1979), 699–702. https://doi.org/10.1016/0028-3932(79)90046-0
[142] Hessel Oosterbeek, Randolph Sloof, and Gijs van de Kuilen. 2004. Cultural Differences in Ultimatum Game Experiments: Evidence from a Meta-Analysis. *Experimental Economics* 7, 2 (01 Jun 2004), 171–188. https://doi.org/10.1023/B:EXEC.0000026978.14316.74
[143] Allan Paivio. 1986. *Mental Representations: A Dual-Coding Approach*. Oxford University Press, New York, NY, USA. https://doi.org/10.1093/acprof:oso/9780195066661.001.0001
[144] Paul E. Panek. 1985. Age Differences in Field-Dependence/Independence. *Experimental Aging Research* 11, 2 (June 1985), 97–99. https://doi.org/10.1080/03610738508259287
[145] Juan Pascual-Leone. 1989. . Ablex Publishing, Westport, CT, USA, Chapter An Organismic Process Model of Witkin's Field-Dependence–Independence., 36–70.
[146] Gordon Pask. 1976. Styles and Strategies of Learning. *British Journal of Educational Psychology* 46, 2 (June 1976), 128–148. https://doi.org/10.1111/j.2044-8279.1976.tb02305.x
[147] Luigi Pizzamiglio and Renzo Carli. 1974. Visual, Tactile and Acoustic Embedded Figures Tests in Patients with Unilateral Brain Damage. *Cortex* 10, 3 (Sept. 1974), 238–246. https://doi.org/10.1016/s0010-9452(74)80016-x

[148] Nataliia Pobiedina, Julia Neidhardt, Maria del Carmen Calatrava Moreno, Laszlo Grad-Gyenge, and Hannes Werthner. 2013. On Successful Team Formation: Statistical Analysis of a Multiplayer Online Game. In *Proceedings of the 2013 IEEE 15th Conference on Business Informatics (CBI '13)*. IEEE Computer Society, Washington, DC, USA, 55–62. https://doi.org/10.1109/CBI.2013.17

[149] George E. Raptis and Christina Katsini. 2021. Analyzing Scanpaths From A Field Dependence-Independence Perspective When Playing A Visual Search Game. In *ACM Symposium on Eye Tracking Research & Applications (ETRA)*. ACM. in progress.

[150] George E. Raptis, Christos Fidas, and Nikolaos Avouris. 2017. Cultural Heritage Gaming: Effects of Human Cognitive Styles on Players' Performance and Visual Behavior. In *Adjunct Publication of the 25th Conference on User Modeling, Adaptation and Personalization (UMAP '17)*. Association for Computing Machinery, New York, NY, USA, 343–346. https://doi.org/10.1145/3099023.3099090

[151] George E. Raptis, Christos Fidas, and Nikolaos Avouris. 2018. Effects of Mixed-Reality on Players' Behaviour and Immersion in a Cultural Tourism Game: A Cognitive Processing Perspective. *International Journal of Human-Computer Studies* 114 (2018), 69 – 79. https://doi.org/10.1016/j.ijhcs.2018.02.003 Advanced User Interfaces for Cultural Heritage.

[152] George E. Raptis, Christos Fidas, and Nikolaos Avouris. 2019. Do Game Designers' Decisions Related to Visual Activities Affect Knowledge Acquisition in Cultural Heritage Games? An Evaluation From a Human Cognitive Processing Perspective. *Journal on Computing and Cultural Heritage* 12, 1, Article 4 (Feb. 2019), 25 pages. https://doi.org/10.1145/3292057

[153] George E. Raptis, Christos A. Fidas, and Nikolaos M. Avouris. 2016. Do Field Dependence-Independence Differences of Game Players Affect Performance and Behaviour in Cultural Heritage Games?. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. Association for Computing Machinery, New York, NY, USA, 38â€“43. https://doi.org/10.1145/2967934.2968107

[154] George E. Raptis, Christos A. Fidas, and Nikolaos M. Avouris. 2017. On Implicit Elicitation of Cognitive Strategies Using Gaze Transition Entropies in Pattern Recognition Tasks. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17)*. ACM, New York, NY, USA, 1993–2000. https://doi.org/10.1145/3027063.3053106

[155] George E. Raptis, Christos A. Fidas, Christina Katsini, and Nikolaos M. Avouris. 2019. A Cognition-centered Personalization Framework for Cultural-Heritage Content. *User Modeling and User-Adapted Interaction* 29 (Mar 2019). Issue 1. https://doi.org/10.1007/s11257-019-09226-7

[156] George E. Raptis, Christina Katsini, Marios Belk, Christos Fidas, George Samaras, and Nikolaos Avouris. 2017. Using Eye Gaze Data and Visual Activities to Infer Human Cognitive Styles: Method and Feasibility Studies. In *Proceedings of the 25th Conference on User Modeling, Adaptation and Personalization (UMAP '17)*. ACM, New York, NY, USA, 164–173. https://doi.org/10.1145/3079628.3079690

[157] Richard Riding and Indra Cheema. 1991. Cognitive Styles - An Overview and Integration. *Educational Psychology* 11, 3-4 (Jan. 1991), 193–215. https://doi.org/10.1080/0144341910110301

[158] Michael Riegler, Mathias Lux, Vincent Charvillat, Axel Carlier, Raynor Vliegendhart, and Martha Larson. 2014. VideoJot: A Multifunctional Video Annotation Tool. In *Proceedings of International Conference on Multimedia Retrieval (ICMR '14)*. ACM, New York, NY, USA, 534:534–534:537. https://doi.org/10.1145/2578726.2582621

[159] Riot Games. 2009. *League of Legends*. Game [Windows]. (October 2009). Riot Games, Los Angeles, California, USA.

[160] Kent A. Rittschof. 2010. Field Dependence-Independence as Visuospatial and Executive Functioning in Working Memory: Implications for Instructional Systems Design and Research. *Educational Technology Research and Development* 58, 1 (Feb 2010), 99–114. https://doi.org/10.1007/s11423-008-9093-6

[161] Eduardo Salas, Terry L. Dickinson, Sharolyn A. Converse, and Scott I. Tannenbaum. 1992. Toward an Understanding of Team Performance and Training. In *Teams: Their Training and Performance*, Robert W Swezey and Eduardo Salas (Eds.). Ablex Publishing Corporation, Norwood, NJ, USA, 3–29.

[162] Katie Salen and Eric Zimmerman. 2004. *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA.

[163] Olivia N. Saracho. 1998. Research Directions for Cognitive Style and Education. *International Journal of Educational Research* 29, 3 (1998), 287–290. https://doi.org/10.1016/S0883-0355(98)00032-9

[164] Kjeld Schmidt. 2002. The Problem with 'Awareness': Introductory Remarks on 'Awareness in CSCW'. *Computer Supported Cooperative Work* 11, 3 (Nov. 2002), 285–298. https://doi.org/10.1023/A:1021272909573

[165] P. G. Schrader and Michael McCreery. 2008. The Acquisition of Skill and Expertise in Massively Multiplayer Online Games. *Educational Technology Research and Development* 56, 5 (01 Dec 2008), 557–574. https://doi.org/10.1007/s11423-007-9055-4

[166] Daniel W. Schwartz and Stephen A. Karp. 1967. Field Dependence in a Geriatric Population. *Perceptual and Motor Skills* 24, 2 (April 1967), 495–504. https://doi.org/10.2466/pms.1967.24.2.495

[167] Magy Seif El-Nasr, Bardia Aghabeigi, David Milam, Mona Erfani, Beth Lameman, Hamid Maygoli, and Sang Mah. 2010. Understanding and Evaluating Cooperative Games. In *Proceedings of the SIGCHI Conference on Human Factors*

in Computing Systems (CHI '10). ACM, New York, NY, USA, 253–262. https://doi.org/10.1145/1753326.1753363

[168] Ian Spence and Jing Feng. 2010. Video Games and Spatial Cognition. *Review of General Psychology* 14, 2 (June 2010), 92–104. https://doi.org/10.1037/a0019491

[169] Jaakko Stenros, Janne Paavilainen, and Frans Mäyrä. 2009. The Many Faces of Sociability and Social Play in Games. In *Proceedings of the 13th International MindTrek Conference: Everyday Life in the Ubiquitous Era (MindTrek '09)*. Association for Computing Machinery, New York, NY, USA, 82–89. https://doi.org/10.1145/1621841.1621857

[170] Tilo Strobach, Peter A. Frensch, and Torsten Schubert. 2012. Video Game Practice Optimizes Executive Control Skills in Dual-task and Task Switching Situations. *Acta Psychologica* 140, 1 (May 2012), 13–24. https://doi.org/10.1016/j.actpsy.2012.02.001

[171] Jonathan Sykes and Melissa Federoff. 2006. Player-centred Game Design. In *CHI '06 Extended Abstracts on Human Factors in Computing Systems (CHI EA '06)*. ACM, New York, NY, USA, 1731–1734. https://doi.org/10.1145/1125451.1125774

[172] Ron Tamborini and Paul Skalski. 2006. The Role of Presence in the Experience of Electronic Games. In *Playing video games: Motives, responses, and consequences.* Lawrence Erlbaum Associates Publishers, Mahwah, NJ, US, 225–240.

[173] Anthony Tang, Jonathan Massey, Nelson Wong, Derek Reilly, and W. Keith Edwards. 2012. Verbal Coordination in First Person Shooter Games. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work (CSCW '12)*. ACM, New York, NY, USA, 579–582. https://doi.org/10.1145/2145204.2145292

[174] Miguel A. Teruel, Elena Navarro, Pascual González, Víctor López-Jaquero, and Francisco Montero. 2016. Applying Thematic Analysis to Define an Awareness interpretation for collaborative computer games. *Information and Software Technology* 74 (2016), 17–44. https://doi.org/10.1016/j.infsof.2016.01.009

[175] Joachim Tiedemann. 1989. Measures of Cognitive Styles: A Critical Review. *Educational Psychologist* 24, 3 (June 1989), 261–275. https://doi.org/10.1207/s15326985ep2403_3

[176] Carolina Tinajero, María Fernanda Páramo, Fernando Cadaveira, and Socorro Rodriguez-Holguin. 1993. Field Dependence-Independence and Brain Organization: The Confluence of Two Different Ways of Describing General Forms of Cognitive Functioning? A Theoretical Review. *Perceptual and Motor Skills* 77, 3 (Dec. 1993), 787–802. https://doi.org/10.2466/pms.1993.77.3.787

[177] Z O. Toups, William A. Hamilton, and Sultan A. Alharthi. 2016. Playing at Planning: Game Design Patterns from Disaster Response Practice. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. Association for Computing Machinery, New York, NY, USA, 362–375. https://doi.org/10.1145/2967934.2968089

[178] Z O. Toups, Jessica Hammer, William A. Hamilton, Ahmad Jarrah, William Graves, and Oliver Garretson. 2014. A Framework for Cooperative Communication Game Mechanics from Grounded Theory. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14)*. ACM, 257–266.

[179] Z O. Toups and Andruid Kerne. 2007. Implicit Coordination in Firefighting Practice: Design Implications for Teaching Fire Emergency Responders. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. Association for Computing Machinery, New York, NY, USA, 707–716. https://doi.org/10.1145/1240624.1240734

[180] Z O. Toups, Andruid Kerne, William A. Hamilton, and Nabeel Shahzad. 2011. Zero-fidelity Simulation of Fire Emergency Response: Improving Team Coordination Learning. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 1959–1968. https://doi.org/10.1145/1978942.1979226

[181] Z O. Toups, Nicolas Lalone, Sultan A. Alharthi, Hitesh Nidhi Sharma, and Andrew M. Webb. 2019. Making Maps Available for Play: Analyzing the Design of Game Cartography Interfaces. *ACM Trans. Comput.-Hum. Interact.* 26, 5, Article 30 (July 2019), 43 pages. https://doi.org/10.1145/3336144

[182] Judy C. R. Tseng, Hui-Chun Chu, Gwo-Jen Hwang, and Chin-Chung Tsai. 2008. Development of an Adaptive Learning System with Two Sources of Personalization Information. *Computers & Education* 51, 2 (Sept. 2008), 776–786. https://doi.org/10.1016/j.compedu.2007.08.002

[183] Deepika Vaddi, Z O. Toups, Igor Dolgov, Rina Wehbe, and Lennart E. Nacke. 2016. Investigating the Impact of Cooperative Communication Mechanics on Player Performance in Portal 2. In *Proc. 42nd Graphics Interface Conf. (GI '16)*. 41–48.

[184] Melissa A. Valentine, Ingrid M. Nembhard, and Amy C. Edmondson. 2015. Measuring Teamwork in Health Care Settings: A Review of Survey Instruments. *Medical care* 53, 4 (2015), e16–e30.

[185] Valve Corporation. 2011. *Portal 2.* Game [Windows]. (April 2011). Valve Corporation, Bellevue, WA, USA.

[186] Valve Corporation. 2013. Dota 2. Game [Windows]. (July 2013). Valve Corporation, Bellevue, WA, USA.

[187] Richard N. van Eck, Hongxia Fu, and Paul V. J. Drechsel. 2015. Can Simulator Immersion Change Cognitive Style? Results from a Cross-Sectional Study of Field-Dependence–Independence in Air Traffic Control Students. *Journal of Computing in Higher Education* 27, 3 (Aug. 2015), 196–214. https://doi.org/10.1007/s12528-015-9099-0

[188] Vero Vanden Abeele, Lennart E. Nacke, Elisa D. Mekler, and Daniel Johnson. 2016. Design and Preliminary Validation of The Player Experience Inventory. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in*

Play Companion Extended Abstracts (CHI PLAY Companion '16). Association for Computing Machinery, New York, NY, USA, 335–341. https://doi.org/10.1145/2968120.2987744

[189] Karlien Vanderheyden and Shari De Baets. 2015. Does Cognitive Style Diversity Affect Performance in Dyadic Student Teams? *Learning and Individual Differences* 38 (2015), 143–150. https://doi.org/10.1016/j.lindif.2015.01.006

[190] Maxime Véron, Olivier Marin, and Sébastien Monnet. 2014. Matchmaking in Multi-player On-line Games: Studying User Traces to Improve the User Experience. In *Proceedings of Network and Operating System Support on Digital Audio and Video Workshop (NOSSDAV '14)*. ACM, New York, NY, USA, Article 7, 6 pages. https://doi.org/10.1145/2578260.2578265

[191] Rodrigo Vicencio-Moreira, Regan L. Mandryk, and Carl Gutwin. 2015. Now You Can Compete With Anyone: Balancing Players of Different Skill Levels in a First-Person Shooter Game. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2255–2264. https://doi.org/10.1145/2702123.2702242

[192] Deborah Waber. 1989. . Ablex Publishing, Westport, CT, US, Chapter The Biological Boundaries of Cognitive Styles: A Neuropsychological Analysis, 11–35.

[193] Greg Wadley, Marcus Carter, and Martin Gibbs. 2015. Voice in Virtual Worlds: The Design, Use, and Influence of Voice Chat in Online Play. *Human-Computer Interaction* 30, 3–4 (2015), 336–365. https://doi.org/10.1080/07370024.2014.987346

[194] Ruth Wageman, J. Richard Hackman, and Erin Lehman. 2005. Team Diagnostic Survey: Development of an Instrument. *The Journal of Applied Behavioral Science* 41, 4 (2005), 373–398. https://doi.org/10.1177/0021886305281984 arXiv:https://doi.org/10.1177/0021886305281984

[195] Yi-Shiang Wang, Chih-Ming Chen, Chin-Ming Hong, and Yen-Nung Tsai. 2013. Interactive Augmented Reality Game for Enhancing Library Instruction in Elementary Schools. In *2013 IEEE 37th Annual Computer Software and Applications Conference Workshops*. IEEE. https://doi.org/10.1109/compsacw.2013.128

[196] Joel S. Warm, William N. Dember, and Peter A. Hancock. 1996. Vigilance and Workload in Automated Systems. *Automation and human performance: Theory and applications* (1996), 183–200.

[197] Karl E. Weick. 1995. *Sensemaking in Organizations*. Foundations for Organizational Science, Vol. 3. SAGE Publications.

[198] Ahuva Windsor. 1983. Sex and Profession as Determinants of Field Dependence. *Perceptual and Motor Skills* 57, 2 (Oct. 1983), 617–618. https://doi.org/10.2466/pms.1983.57.2.617

[199] Herman A Witkin and Donald R Goodenough. 1977. Field Dependence and Interpersonal Behavior. (1977), 661–689 pages. https://doi.org/10.1037/0033-2909.84.4.661

[200] Herman A. Witkin, Donald R. Goodenough, and Stephen A. Karp. 1967. Stability of Cognitive Style from Childhood to Young Adulthood. *Journal of Personality and Social Psychology* 7, 3, Pt.1 (1967), 291–300. https://doi.org/10.1037/h0025070

[201] Herman A. Witkin, C. A. Moore, Donald R Goodenough, and P. W. Cox. 1977. Field-Dependent and Field-Independent Cognitive Styles and Their Educational Implications. *Review of Educational Research* 47, 1 (1977), 1–64. https://doi.org/10.3102/00346543047001001

[202] Jason Wuertz, Sultan A. Alharthi, William A. Hamilton, Scott Bateman, Carl Gutwin, Anthony Tang, Z O. Toups, and Jessica Hammer. 2018. A Design Framework for Awareness Cues in Distributed Multiplayer Games. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3173574.3173817

[203] Jason Wuertz, Scott Bateman, and Anthony Tang. 2017. Why Players Use Pings and Annotations in Dota 2. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 1978–2018. https://doi.org/10.1145/3025453.3025967

[204] Nick Yee. 2006. Motivations for Play in Online Games. *CyberPsychology & Behavior* 9, 6 (2006), 772–775. https://doi.org/10.1089/cpb.2006.9.772 arXiv:https://doi.org/10.1089/cpb.2006.9.772 PMID: 17201605.

[205] José P. Zagal, Jochen Rick, and Idris Hsi. 2006. Collaborative Games: Lessons Learned from Board Games. *Simulation & Gaming* 37, 1 (2006), 24–40. https://doi.org/10.1177/1046878105282279 arXiv:https://doi.org/10.1177/1046878105282279

[206] Sebastian Zander, Ian Leeder, and Grenville Armitage. 2005. Achieving Fairness in Multiplayer Network Games Through Automated Latency Balancing. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology (ACE '05)*. ACM, New York, NY, USA, 117–124. https://doi.org/10.1145/1178477.1178493

[207] Li-fang Zhang. 2006. Does Student-Teacher Thinking Style Match-Mismatch Matter in Students' Achievement? *Educational Psychology* 26, 3 (2006), 395–409. https://doi.org/10.1080/01443410500341262 arXiv:https://doi.org/10.1080/01443410500341262

APPENDIX A: SEMI-STRUCTURED INTERVIEW GUIDE

Stage	**Sample questions / directions**
Warming-Up	- Brief explanation of the process. - Brief talk about player profile and background.
Player Experience	- Can you describe the playing experience? Things you liked, you didn't like etc. - Pros and cons of the game? - Did you feel stressed with the time limit during the game? Why? - Did you feel stressed with the tasks you had to complete? Why? - Did you feel your team was efficient? Why? - Could you easily identify what you were expected to do?
Game mechanics	- How was your time split between the map and 3D gameworld? - What did you use the map and 3D gameworld for? - What interactions did you make? - How did you explore the gameworld? - Did you have any specific preference regarding the game mechanics?
Communication	- How did you communicate with your partner? - What communication channel did you use most? - Why did you communicate for? - Did you use the annotations feature? How?
Collaboration	- How would you describe the collaboration with your partner? - How did you coordinate with your partner? - Were you aware of the what your partner was doing all the time? How? - Were you aware of the where your partner was? How?
Miscellaneous	- Is there anything else you would like to comment about the game or the collaboration?
Finish	- Summary of the most important points raised in the interview. - Acknowledgments and leave-taking

❗ Please note that this is a guide of questions used during the interview. However, the researchers omitted questions for which answers transpired previously, or asked questions in efforts to probe more information.

APPENDIX B: *TeCP* VIDEO

The video of the *TeCP* game has been submitted as supplementary material.

APPENDIX C: STATISTICAL ANALYSIS

Team Performance

	Completion time (seconds)
FD-FD team	M = 650.784, SD = 193.323
FD-FI team	M = 439.570, SD = 125.027
FI-FI team	M = 402.909, SD = 114.591

	Observed difference
FD-FD — FD-FI	211.223 (95% CI: 36.421 to 386.012, p = .015)
FD-FD — FI-FI	247.870 (95% CI: 73.082 to 422.672, p = .004)
FD-FI — FI-FI	37.223 (95% CI: -143.057 to 217.502, p = .998)

Cognitive Workload: Mental Demand

	NASA-TLX Points
FD-FD team	M = 60.000, SD = 14.177
FD-FI team	M = 43.333, SD = 11.136
FI-FI team	M = 42.222, SD = 10.171

	Observed difference
FD-FD — FD-FI	16.667 (95% CI: 1.045 to 32.288, p = .038)
FD-FD — FI-FI	17.787 (95% CI: 3.188 to 32.368, p = .017)
FD-FI — FI-FI	1.111 (95% CI: −13.388 to 15.610, p = 1.000)

Cognitive Workload: Physical Demand

	NASA-TLX Points
FD-FD team	M = 20.778, SD = 8.172
FD-FI team	M = 16.222, SD = 7.596
FI-FI team	M = 19.889, SD = 7.288

	Observed difference
FD-FD — FD-FI	4.556 (95% CI: −4.496 to 13.607, p = .623)
FD-FD — FI-FI	.889 (95% CI: −8.163 to 9.941, p = 1.000)
FD-FI — FI-FI	−3.367 (95% CI: −12.719 to 5.385, p = .923)

Cognitive Workload: Temporal Demand

	NASA-TLX Points
FD-FD team	M = 49.111, SD = 14.461
FD-FI team	M = 40.222, SD = 9.922
FI-FI team	M = 37.778, SD = 16.962

	Observed difference
FD-FD — FD-FI	8.889 (95% CI: −8.201 to 25.978, p = .580)
FD-FD — FI-FI	11.333 (95% CI: −5.756 to 28.423, p = .302)
FD-FI — FI-FI	2.444 (95% CI: −14.645 to 18.534, p = .998)

Cognitive Workload: Performance

	NASA-TLX Points
FD-FD team	M = 60.000, SD = 19.183
FD-FI team	M = 64.167, SD = 16.763
FI-FI team	M = 86.389, SD = 11.281

	Observed difference
FD-FD — FD-FI	−4.161 (95% CI: −23.511 to −15.410, p = .989)
FD-FD — FI-FI	−26.387 (95% CI: −50.016 to −2.615, p = .030)
FD-FI — FI-FI	−22.223 (95% CI: −43.970 to −.475, p = .045)

Cognitive Workload: Effort

	NASA-TLX Points
FD-FD team	M = 51.556, SD = 14.976
FD-FI team	M = 46.333, SD = 9.760
FI-FI team	M = 39.778, SD = 7.067

	Observed difference
FD-FD — FD-FI	5.222 (95% CI: −8.242 to 18.686, p = .984)
FD-FD — FI-FI	11.778 (95% CI: −1.686 to 25.242, p = .101)
FD-FI — FI-FI	6.556 (95% CI: −6.908 to 20.019, p = .667)

Cognitive Workload: Frustration

	Completion time (seconds)
FD-FD team	$M = 47.500$, $SD = 19.743$
FD-FI team	$M = 29.722$, $SD = 21.200$
FI-FI team	$M = 20.833$, $SD = 16.617$

	Observed difference
FD-FD — FD-FI	17.778 (95% CI: −5.615 to 41.171, $p = .187$)
FD-FD — FI-FI	26.667 (95% CI: .378 to 52.955, $p = .046$)
FD-FI — FI-FI	8.889 (95% CI: −14.504 to 32.282, $p = 1.000$)

Non-verbal Communication

	Annotations drawn
FD-FD team	$M = 6.556$, $SD = 193.323$
FD-FI team	$M = 9.171$, $SD = 125.027$
FI-FI team	$M = 6.221$, $SD = 114.591$

	Observed difference
FD-FD — FD-FI	−2.556 (95% CI: −4.547 to −.564, $p = .010$)
FD-FD — FI-FI	.333 (95% CI: −2.198 to 2.867, $p = 1.000$)
FD-FI — FI-FI	2.889 (95% CI: .898 to 4.880, $p = .004$)