COLOR WALKS IN THE CITY

PSYCHO-PHYSIOLOGICAL RESPONSES TO URBAN ENVIRONMENTS: VIRTUAL AND FIELD EXPERIMENTS TO EVALUATE THE IMPACT OF COLORFUL INTERVENTIONS ON GAZE, AFFECTIVE STATES AND SPONTANEOUS WALKING

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Dedicated to my husband Clément

and to my daughter Néphéli.

ABSTRACT

My thesis examines how colorful designs projected within an urban environment can enhance pedestrian experience. To examine this question, we co-designed colorful floor markings and evaluated their impact on walking experience by using methods of affective sciences, experimental psychology and design.

A series of laboratory-based studies were first conducted to determine scientifically-based design principles. In Study1, gaze behaviour and facial thermal responses to colour patches were measured with the aim to identify which colors capture attention and trigger positive affective states. Study2 was an online experiment to test the effects of different design scenarios of colorful sidewalks. The goal here was to identify the colors that would be perceived positively, when projected in the urban space. Study 3 was a virtual reality experiment in which gaze behaviour and affective states of pedestrians were measured in environments that used the colors and designs from studies 1 and 2. A total of six design scenarios were created to confirm the restorative effects of nature and of color designs during spontaneous walking. These studies offered a set of scientifically-based design principles that were then projected in the field case study of Playful' City.

Three ecological studies were run to test these principles. Study 4 examined the effects of colorful crossroads on the affective and cognitive states of students discovering the University campus of Lille. Study 5 tested the impact of color lines and colorful painted patters on spontaneous walking and perceived pleasantness of walking though the campus. Finally, study 6 compared the impact of color designs placed in an urban and in a nature environment. In these three studies, a combination of self-declared evaluations and objective measurements was used to assess walkers' responses to the environment pre-post design interventions. Valence, heart rate, electro-dermal activity and cognitive load were measured collectively. Overall, my work offers new avenues towards the conception and the evaluation of urban design.

Keywords: field experiments; affective sciences; experimental psychology; design; virtual reality; well being

Ma thèse porte sur la façon dont les dessins colorés projetés dans un environnement urbain peuvent améliorer l'expérience des piétons. Pour examiner cette question, nous avons co-conçu des marquages au sol colorés et évalué leur impact sur l'expérience des piétons en utilisant des méthodes de psychologie cognitive.

Une série d'études en laboratoire a d'abord été menée pour déterminer des conceptions de design scientifiquement fondées. Dans l'étude 1, nous avons mesuré le positionnement du regard et les réponses thermiques du visage avec 32 couleurs. Dans l'étude 2, qui est une expérience en ligne, les trottoirs colorés ont été perçus comme réparateurs (par évaluation d'images). L'étude 3, était une expérience de réalité virtuelle dans laquelle le comportement du regard et les états affectifs des piétons ont été mesurés. Au total, six scénarios d'aménagement différents ont été créés pour confirmer les effets réparateurs de la nature et des couleurs pendant la marche spontanée. Ces études ont permis de dégager un ensemble conception de design fondé sur des données scientifiques, qui a ensuite été projeté dans l'étude de cas "Playful" City.

Trois études écologiques ont été menées pour tester ces principes. Les résultats de l'étude 4, rendent compte des effets des carrefours colorés sur les états affectifs et cognitifs des étudiants découvrant le campus universitaire. L'étude 5, a permis d'observer l'impact des lignes de couleur et des motifs peints colorés sur la marche spontanée et la plaisir perçu de la marche dans le campus. Enfin, l'étude 6 a permis de comparer l'impact des motifs colorés placés dans un environnement urbain ou dans un environnement naturel. Dans ces trois études, une combinaison de mesures autodéclarées et objectives a été utilisée pour évaluer les réactions des marcheurs à l'environnement avant et après les interventions de design. La valence, la fréquence cardiaque, l'activité électrodermale et la charge cognitive ont été mesurées. Globalement, mon travail offre de nouvelles pistes pour la conception et l'évaluation de l'aménagement urbain.

Keywords: expériences de terrain; sciences affectives ; psychologie expérimentale ; conception ; réalité virtuelle ; bien-être

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Part I

GENERAL INTRODUCTION

1

INTRODUCTION

Cities are designed to protect and meet the needs of humans. However, studies suggest that living in a congested urban environment is unhealthy, and it is one of the first factors that has a detrimental impact on people's physical and mental health (Sarkar & Webster, 2017). Urban citizens are vulnerable to obesity (Booth et al., 2005), to depression (Galea et al., 2005a) and to stress (Lederbogen et al., 2011a). Therefore, it must be a significant shift in research and policy toward preventive interventions. To encourage a healthier lifestyle in the built environment, urban remodeling must be rethought.

Research has proven that walking can be an important preventive tool for physical (Murtagh et al., 2010) and mental (Maki et al., 2012) health. What makes a place walkable has become a matter of design priority. Walkability is defined as "the extent to which walking is easily accessible as a safe, connected, accessible and enjoyable mode of transportation" (Shamsuddin et al., 2012). As such, it has become a key design solution for sustainable urban environments that promote physical and mental well being. However, numbers report that less than 30% of the word population engage in spontaneous walking and regular walking behaviors. Research indicates the important relationship between the built environment and walking behavior (Moura et al., 2017) and highlights that feelings of pleasure, comfort and moderate sensory stimulation are crucial for the walking experience (Appolloni et al., 2019; Bornioli et al., 2019). The question is now to gain a better understanding of how design nudges may be able to create positive walking experiences and encourage spontaneous urban walking.

In order to create design solutions that promote walking, we need to nudge walker's behavior in their daily lives.The Theory of affordances says that humans have an embodied perception of the environment and that the environment constantly is presenting them a variety of artifacts that lead to possible behaviors,inviting them to act (Gibson, 1979b). More recently, cognitive psychology has proposed that simply looking at an object can generate automatic action motor planning towards that object (Nazir et al., 2017). Therefore, environmental perception and design interventions could affect our intention to walk.Nudging, being a design tool for guiding user behavior, can be used to apply theory of affordance to promote urban walking.The term "nudges" refers to low-cost and easy to make architecture choices and interventions that aim to guide a user's behavior without constraining it (Sugden, 2009). Thus, a closer examination of nudge design is required.

Nudge methods have proven to be effective in domains like, marketing (Goldstein et al., 2008), (Arno & Thomas, 2016) public health and Social media (Pennycook et al., 2020). Nudging has previously been employed in the urban environment to promote healthy behaviors such as, putting banners or posters with varied slogans near stairwells or escalators to encourage stair use (Hongu et al., 2019), diffusion of ambient odors(Leenders et al., 2019), offering financial rewards(Hoenink et al., 2020). However, nudge design to promote positive behavior change towards walking has yet to be thoroughly investigated in the built environment. The question is now how design nudges may be able to encourage spontaneous urban walking.

Recent work has focused specifically on subjective affective states was shown to be critical in guiding behavior (Caravà & Scorolli, 2020). Humans choose actions that are more likely to make them feel good and less likely to make them feel bad (Lowe, 2011). It is claimed that environmental artifacts can not only afford cognitive and motor actions but also generate affective components, the feelings that a person has when confronted with an object of attitude, that will impact their action tendencies. In my thesis, I will investigate nudges from the perspective of cognitive psychology, looking at the objective and subjective affective states of walkers, with the goal of demonstrating that colorful interventions might increase positive pedestrian experiences and promote walking.

1.2 FLOOR MARKING

Floor marking is a typical nudging approach used on public areas for rezoning public space, temporary transform spaces, and directing pedestrians to the city's interest zones.Colorful floor marking is more cost-efficient, practicable, and effective than other design options. However, no research has been conducted to see if this design method has a beneficial and efficient effect on walkers. Figure 1 below show examples of this design nudging method.

Figure 1: Examples of urban floor marking.

(a) Superkilan Copenhague.

(b) Franklinstraat, Eindhoven, Netherlands.

The great majority of children do not get the recommended 60 minutes of moderate-intensity physical activity on a daily basis. Painted floor markings were employed as a design solution to encourage pupils to be more physically active during recess because they are a low-cost and easy-to-install intervention. Previous studies examined the effectiveness of these types of interventions by taking anthropometric measurements before and after the interventions and using biometric monitoring equipment(Blaes et al., 2013; Ridgers et al., 2007; Stratton & Mullan, 2005).The main outcomes of these studies suggest that colored floor markings increased students physical activity levels and their energy output during sports activities. As a result, painted markings are a popular new design solution for encouraging physical activity during recess (See Figure 2).

Figure 2: Example of playful school marking

Outside of schools, there has not been much research done on floor markings. Research explored the technique of floor marking in public spaces, targeting a wider range of populations (Nikolopoulou et al., 2016a). In both public and private spaces, a series of pilot investigations have been conducted. The road markings were chosen to facilitate pedestrian movement and identify areas of attraction without interfering with pedestrian traffic flow. They selected bright colors such us pink and yellow to make the lines stand out but not be mistaken for public safety lines. Colored floor markings were found to have an impact on walkers' direction, speed, and number of stops. The research, on the other hand, evaluated the interventions by observing only the users from the outside. They looked at walking behavior as a symptom, rather than the users' internal affective and cognitive state, which explain the cause of their walking behavior. Figure 3 below demonstrates the interventions of this study.

Figure 3: Interventions Nikolopoulou, 2016.

(a) Tape Lines. (b) Tape Maze.

1.3 NEUROSCIENTIFIC METHODS FOR AFFECTIVE TESTING IN NATURAL ENVIRONMENTS

In the past, the primary approaches for determining the impact of the environment on the walker were focused on observing pedestrian movement. The key study topics were about pedestrian safety, density and flow. The methods used at the time were mainly, video recording (Holliday et al., 1990), on-site hand recording (Walmsley & Lewis, 1989), pedestrian counting (Hocherman et al., 1988) and self reported evaluations (Jonah & Engel, 1983). The feelings of the pedestrian during his journey had not yet been addressed.

Researchers are able to acquire more data on pedestrian density and movement as technology advanced with the use of tools of detection such as GPS (Hahm et al., 2017) and sensors (Gidel et al., 2010). At the same time the evolution of urban society and the frantic pace of the city created concerns about environmental stress, well-being, pedestrian comfort and health. As a result, researchers began to focus their attention not just on pedestrian mobility but also on their psychological and physiological states.

Self-reporting remained the main methodological approach for investigating the psychological aspects of pedestrians. The main methods that are used are surveys (Knöll et al., 2018), participatory photo methods (Miaux et al., 2010) and walking diaries (Sun et al., 2014). The intensity and duration of the user's walk were primarily measured to determine the physiological component of the pedestrians by using methods such as, accelerometers (Prandi et al., 2014), pedometers (Sisson et al., 2008) and by taking into account anthropometric measurements (Blaes et al., 2013).Even when external trials enhanced their methodologies and data entry technology, the primary methodological approach stayed the same as it is based on self-evaluation and observation of the user's external behavior.

New technologies such as eye tracking, are being used by cognitive psychology in lab-based investigations to analyze the affective and cognitive states of humans when exposed to different environmental scenarios (Zhang & Park, 2021).With the term Affect, we refer to the psycho-physiological responses to the interaction of human with the environment. It describes a broad term of feelings such as pleasantness of an experience, that a person can have, consciously or unconsciously, towards an event or a stimulus (Batson et al., 1992a).With the term Cognitive we refer to the mechanics by which animals and humans obtain, process, store, and act on environmental information (Shettleworth, 2009).

The advances in cognitive methodologies is allowing us to investigate the impact of various design components, which will offer the first scientifically-based design principles.

However, laboratory-based results raise the question of whether these methods can be used to predict and explain real-world behaviors. With the help of mobile technologies, a modest but expanding corpus of research aims to comprehend the human-environment interaction beyond self-reports and external observations, and outside the controlled walls of a research laboratory.

1.4 PHD SUMMARY AND OBJECTIVES

The general question of my PhD project was to examine how colorful designs projected within an urban environment can impact the affective and the cognitive states of the walkers, with the goal to guide the design principles to nudge pedestrian behavior.

- First Objective: Focus on the psychological and physiological states of the pedestrians, by using objective and subjective measurements.
- Second Objective: Bridge the gap between cognitive methods and design, by using pre-post measurements with individual testing.
- Third Objective: Use multidisciplinary approaches to better deploy nudge designs that encourage city walking by using different methods for evaluating the design interventions.

These objectives were accomplished in two parts. The first part of my thesis consist of three laboratory experiments ;The purpose of this phase was to test the impact of different colors and designs on pedestrians in a controlled environment.

Study 1: Measure of changes in gaze behaviour and facial thermal responses to 32 colour patches

Study 2: Evaluate perceived restorative effects and stress levels in adults watching multi-image colourful sidewalks (an online experiment)

Study 3: Measure of changes in gaze behaviour and affective states in pedestrians when walking different design scenarios (a virtual reality experiment)

The second part of my thesis presents a series of real-life field experiments; The goal was to evaluate a selection of scientifically based colorful designs in a real-life environment.

Study 4: Compare the impact of colorful markings on crossroads.

Study 5: Test the impact of color lines and colorful painted patterns on spontaneous walking and perceived pleasantness when walking through campus.

Study 6: Compare the impact of color designs placed in an urban and in a nature environment.

The work performed was in collaboration with the MEL (Métropole de Lille) and the CNRS research federation EQUIPEX *Science et Culture du Visuel* (Tourcoing).

Part II

LAB EXPERIMENTS

2

STUDY 1: FACIAL THERMAL RESPONSES TO COLORS

In preparation for publication in: Journal of the Academy of Marketing Science

TITLE: Designing effective moodboards: a method to benchmark moodboards using gaze and facial thermal responses to colors and words

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2.1 INTRODUCTION

A moodboard is a collage of photographs, text, and samples of various objects. It can have a certain theme or any material selected at random. But the purpose of moodboards is to quickly inform others of the overall "feel" or "flow" of an idea. Moodboards are also used in commercial marketing campaigns to sell a product or a service (Cassidy, 2011). Hence, they are powerful visual tools through which designers and marketers can communicate concept ideas to an audience not by a descriptive way but through an emotional channel. Indeed, a well-designed moodboard will have the power to trigger changes in an observer's emotional state, a phenomenon that is known to influence decision making (Achar et al., 2016a). As the goal of a moodboard is to generate specific emotions coding for the product or the service that it represents (Williams et al., 2008), the quality of a moodboard content can be evaluated by considering how well the visual is able to reveal the 'mood' of the design idea (Baxter, 1995), which in turn will guide the observers' emotional experiences (Eckert & Stacey, 2000; McDonagh & Denton, 2005).

Emotional states are known to influence decision making (Achar et al., 2016b). A wide selection of studies has even demonstrated that specific emotions, even when they are incidental to the decision at hand, can significantly impact individuals' perceptions, judgments, and decisional behavior (Agrawal et al., 2013; Keltner & Lerner, 2010).Consequently, well designed moodboards can influence the decision that an observer is about to make. The goal of the present study was to develop a method to benchmark visuals applicable by the sports industry to trigger desire to engage in leisure physical activity.

The construction of a quality moodboard is a complex task. Designers will attribute time and effort to collect materials of different, e.g., colors, textures, and shapes. Complex images can also be gathered from magazines and online sources, the general goal being to gather as many items as possible to formulate the visual aesthetics of the future visual (Taleb, 2012). But little has been done to define a method to create impacting and efficient moodboards. In recent years, general guidelines have started to emerge about what principles should be featured in a "good" moodboard. Design recommendations indicate that moodboards should possess the cognitive and aesthetic operations of discretization, coherence, and relevance (Gentes et al., 2015). But such guidelines do not offer objectively based judgments. It remains difficult to evaluate exactly whether the observer is truly experiencing the mood that the designer intended to communicate (Garner & McDonagh-Philp, 2001).

Another difficulty stands in the fact that individuals may have diverging perceptions as a function of their e.g., personality, social background and state of mind. Indeed, from a psychological point of view, it is conceivable that moodboards may trigger contrasting emotional responses in a viewer accordingly to what is meaningful for that person. Colors, symbols and words can trigger distinct percepts and as a consequence, the visual content of the moodboards need to be adapted to each target population. In the present work, our goal was to use complementary neuroscientific methods, gaze and thermal responses to select the background color as well as the words used to create motive-specific moodboards as a function of the motives that may trigger inactive individuals to decide to start exercising.

In the sport industry, commercial moodboards aim to provoke the desire to buy a product or to sign up in a sports club. However, moodboards can also be used in health psychology to trigger the intention to engage in physical activity for health benefits. However, in such a case, because of the biaised perception of effort in inactive individuals (Carlier et al., 2017) it is essential to select the appropriate visuals and concept elements that will trigger the adequate storyline. A person running through the streets of New York provides a different idea than that of a man lifting weights in a fitness room. The illustrated context of the sportsmen communicates contrasting ambiences (lights, odors, sounds) and intensities of practice. Hence, focus must be placed on the type of activities, the facial expressions as well as the backgrounds used – outdoor/indoor; individual/group; at work/at home. The correct selection of these factors will help viewers to imagine themselves performing the activity and trigger the thought of investigating time to practice for health objectives. Recent studies in sport psychology have reported that the intrinsic motivation (Teixeira et al., 2012) and the pleasure experienced during a practice session (Zenko et al., 2016) are particularly important for physical exercise adherence. Such empirical observations were confirmed in a study demonstrating that adding the emotional appraisal as a variable in a predictive model increased the quality of the prediction (Mohiyeddini et al., 2009). Hence, it is of importance to consider not only the storyline but also the emotional messages that will touch upon positive affective memories (Kiviniemi et al., 2007; Williams et al., 2008) to trigger the decision to act.

The work presented here was aimed at validating the design process for creating emotional impacting visuals to inactive adults that expressed different motives that would encourage the decision to exercise. A moodboard illustrating a body-built sweating male running through the streets of New York may convey positive emotions in a person who is highly tolerant to effort - who engages weekly in strength building. But this same moodboard will trigger a series of negative emotions in a person searching for soft physical activities that bring serenity and appeasement. For this later viewer, a picture of a person in a park engaged in slow Taiichi movements may be more effective. Based on the self-determination theory (Ryan & Deci, 2000), a total of three intrinsic motivation types were selected in the present study using the PALMS questionnaire (Molanorouzi et al., 2014). We focused on physical strength, psychological well-being, and appearance, which are internal motivators that have been reported to be key factors for sustainable physical active life-styles (Biddle et al., 2021). In the following sections, eye-tracking (task 1) and motor chronometry procedures (task 2) were used to select the visual elements that were then used to create moodboards that would echo the internal motives of participants possessing three different types of motivation profiles. The first assumption underlying this body of work was that testing isolated features (colors and words in tasks 1 and 2, respectively) will give informative cues on how to construct more complex visual content. The second assumption was that the affective experiences triggered in the viewers could be captured as a slight but systematic change in facial thermal temperature (task 3). Such patterns of results will confirm that the designed moodboards encapsulated information that have the power to reach out specifically to the target motivation subgroup.

2.2 TASK 1: EYE-TRACKING TO SELECT MOODBOARD COLORS

Eye tracking is a technique whereby the position of the eye is used to determine gaze direction of a person at a given time and also, the spatial trajectories following by the eyes as a function of time (Poole & Ball, 2006). As the link between eye movements and visual attention has been widely demonstrated (Deplancke et al., 2011), eye tracking methods are highly relevant to investigate the unconscious processes that are at the core of attention processing and decision making.

Two different types of visual attention mechanisms are known to work simultaneously (Connor et al., 2004; Posner et al., 1980). Bottom-up processes (exogenous attention) are driven by sensory inputs and trigger fast, automatic and unconscious gaze orientations towards the most salient part of a visual scene. When an individual is exposed to a new visual content, these mechanisms are generally responsible for the preparation and triggering of the first saccades. The parameters that have been shown to trigger these automatic reflex-type responses are high visual contrasts (Näsänen et al., 2001) and salient colors (Gelasca et al., 2005).

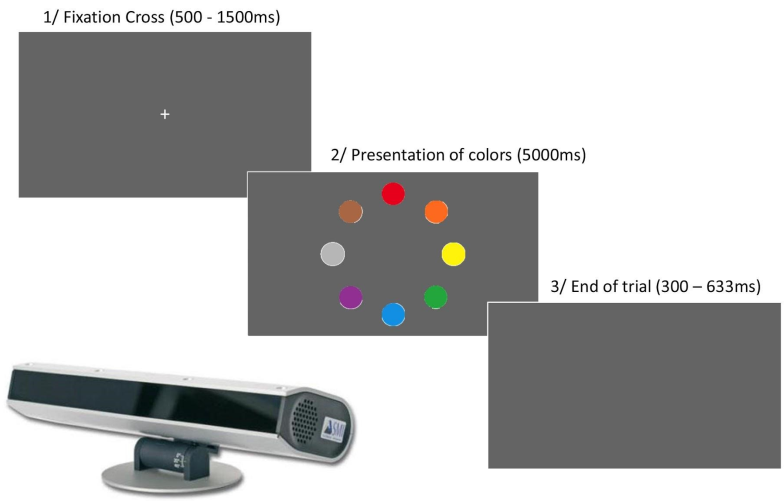
The top-down processes are controlled mechanisms that become efficient through life experiences (Gilbert & Sigman, 2007). They are driven by endogenous attention and are typically useful when individuals are seeking for particular information in the environment (e.g., when searching for a familiar face in a crowd). In such a task, an individual must retrieve a visual object that is stored in memory and control a visual search strategy to find a match. Such processes are also activated when selecting favorite items amongst non-preferred ones. It is possible to quantify these late behavioral indices by measuring the total amount of saccades directed towards a particular region of a visual scene or the total time spent looking at a given item of interest. Studies on esthetical preferences have reported that the number of saccades and the total durations of gaze can be used as sensitive indicators to assess the correlation between visual (objective) and declared (subjective) preferences (Griffey & Little, 2014).

In the present task, little differences are expected for the first saccades between profile-types because attention and thus, eye movements will be guided by the salient properties of the visual items. Red colors should attract the eye first (Gelasca et al., 2005). However, during intentional visual search, the colors preferred for possible sportswear should be motive-specific. Endogenous orientation of attention should lead to longer and more frequent saccades towards the preferred colors, differentiating the inner motives of each motivation profile.

2.2.1 *Population, task and procedure*

A total of 250 participants aged between 18 and 35 years of age were invited to complete a numerical format of the PALMS on a lime survey platform. Participants were contacted through social media through the university website. From the eight sub-scales existing in the PALMS, individuals responding specifically to one of the three following sub-scales only were considered: psychological well-being (PSY - Relax and Balance), appearance (APP – Feel Beautiful) and physical strength (PHY – Feel Strong). After controlling for self-declared quantity of physical activity per-

Figure 4: Preferences for colors as a function of motivation profiles were determined using an eye-tracking procedure during which patches of colors were presented in the center of the screen. Saccadic latencies to the first patch and fixation durations were measured for picture presentations of 5 seconds (SMI RED 120 eye-tracking system).

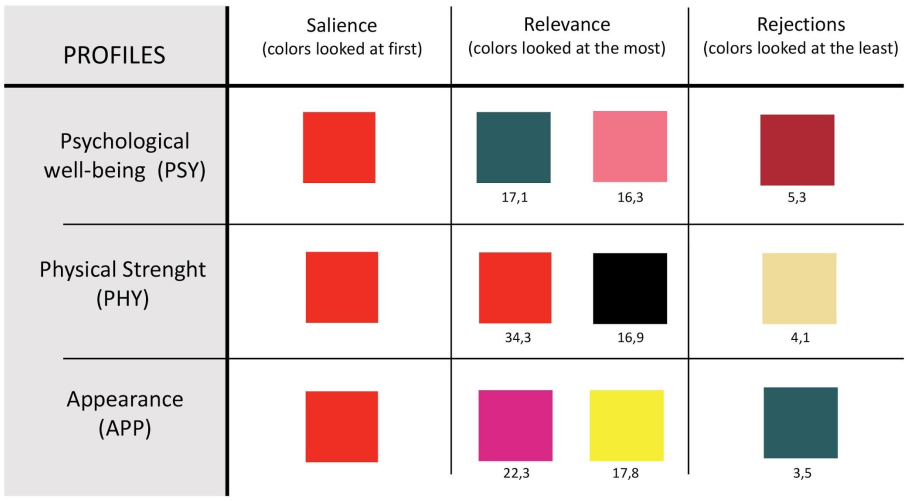


formed per month (using the IPAQ questionnaire, (Craig et al., 2003)), a total of 45 moderately-active individuals were invited to come into the laboratory. A total of 15 PHY men, 15 PSY women and 15 APP women accepted the invitation (Mage = 22.85 ± 4.78 years, MBMI = 24.89 ± 5.76 kg.m-2) and participated in two experimental sessions conducted one month apart. Before participating in the study, each volunteer read an information letter and completed a written consent form. The study was approved by the Ethics Committee for behavior human studies of the University of Lille. See Figure 4

Participants were seated in front of a screen–mounted eye tracker (SMI RED) with a sampling rate of 120 Hz. This portable system is easy to calibrate and permits participants to seat comfortably facing a screen without the need of a chin-rest. The experiment was conducted within a silent and dark room and lasted approximately 20 minutes.

A total of 32 patches of colors were presented on a screen by groups of 8 patches at a time, placed around a virtual circle (Figure 4). The screen background was light grey. The participant's task was to look at the different color patches to determine which color they would select while purchasing new exercise t-shirts. For each screen, the reaction times of the first saccade to each color patch was measured as the time taken by the fovea to focus from the central cross to the center of each patch, for the first time. This measure was taken as an indicator of visual salience. Then, for each color patch (area of interest), the mean gaze duration was calculated as the mean cumulative durations of the consecutive gaze fixations throughout a trial. This measure was taken as an indicator of relevance (the longest gaze duration) and rejection (the shortest gaze duration), which we hypothesized would be different as a function of motivation profile. There was a total of 80 trials presented in a randomized order, with 30 second-breaks between blocks of 20 trials. Stimuli display and response recordings were controlled using MATLAB 7.6.0. software including the Psychophysics Toolbox ptb-3 (Brainard & Vision, 1997; Pelli & Vision, 1997). The gaze responses were analyzed for each participant in three steps. First, the sum of gaze durations to the first color patch across all trials was calculated as indicator of the most salient color as a function of motivation profile. Then, the mean gaze duration across trials was calculated for each color. Finally, for each profile, all colors were ranked as a function of the total duration of gaze fixation across all trials (the first being the color characterized with the longest fixation duration). For the statistical analysis, the 5 top ranked colors were considered only. An analysis of variance was conducted first on mean gaze fixation durations with Profile (PSY; PHY; APP) as independent variable. Then, a repeated measures ANOVA was conducted on the mean gaze fixation durations as a function of Profile and Ranking position. The alpha significance level was set to 0.05. Throughout these analyses, partial eta squares (2p) were calculated to report the effect sizes. Bonferroni-adjusted pairwise comparisons were used when required for post-hoc analyses.

Figure 5: Color patches that were found to be the most salient (left), the most relevant (middle) and the least relevant (right) as a function of the motivation profile. The values presented correspond to the mean fixation durations (in seconds) spent on each color patch..



2.2.2 *Results and discussion*

There was a significant effect of Profile on mean duration of gaze fixation (F(2,42) = 10.138, p = 0.001, 2p = 0.325). The APP group was characterized with shorter gaze fixations (8.781 s +/- .361 s) than the PHY (10.217 +/- .461 s) and the PSY (11.045 +/- .366 s). Nevertheless, they revealed similar top salience patch with all Profiles fixating first barbaros cherry (Figure 2-left). This color was on average the first patch looked at in 29.5 % of the cases.

When considering the relevance, the results were specific to each Profile. PSY individuals preferred the patches in shades of green and pastel but spent little time looking at the reds. PHY profiles remained attracted to strong reds and black color patches for significantly longer fixation durations than the other profile types. The pastel patches were the least relevant. Finally, the APP individuals spent the most time looking at the pink and the bright yellows, with very little interest shown to the green and darker colors. These results are illustrated in Figure 5, which reports the color relevance and rejections, as a function of profile type.

When taking into account the ranking, the statistical results indicated that the most relevant color was indeed fixated the longest compared to the four following top ranked colors ($F(4,168) = 4.331$, $p = 0.003$, $2p = 0.094$). The Profile main effect was not significant ($F(2,42) = 0.762$, $p = 0.473$, $2p = 0.035$), indicating that for all three profiles, the color ranked as first was fixated the longest, discriminating it from all other color patches. There was an absence of Profile * Ranking interaction, which suggested color preference was significant in all groups, fixating especially one color longer than all the others ($F(2,42) = 0.762$, $p = 0.473$, $2p = 0.035$).

The findings reported in this first task confirmed that red was a salient color, which is a universal finding. When considering the preferred colors that individuals looked at, a contrasting orientation of gaze for colors was observed as a function of motivational profiles. Colors have always played a significant role in impacting one's moods, sensations and perception. Different signs merge in a person's experience of a product as colors do not function separately and individually, but form multi-layered references and can influence a consumer's purchase decision. Following the results obtained in this first task, the relevant colors of t-shirts for each profile type were used as background textures for the leisure-sport moodboards that were designed and tested in task 3.

2.3 TASK 2: MOTOR CHRONOMETRY TO SELECT WORDS

The literature about decision making and especially, the time required to make a decision has often been related to the cognitive processes required for response selection and certainty solving as well as motor preparation (Kiani et al., 2014). Research has reported that long reaction times are associated to complex internal operations and uncertainty, for example when an individual fails to retrieve a word from memory

(Fawcett & Taylor, 2008) or when a difficult choice must be made by conflict solving (Gilbert & Sigman, 2007). Short reaction times are, on the contrary, related to reactive, automatic simple and easy-to-take decisions. This is case for example when individuals must choose between favorite foods even if interferences are possible by physiological needs (Finlayson et al., 2007).

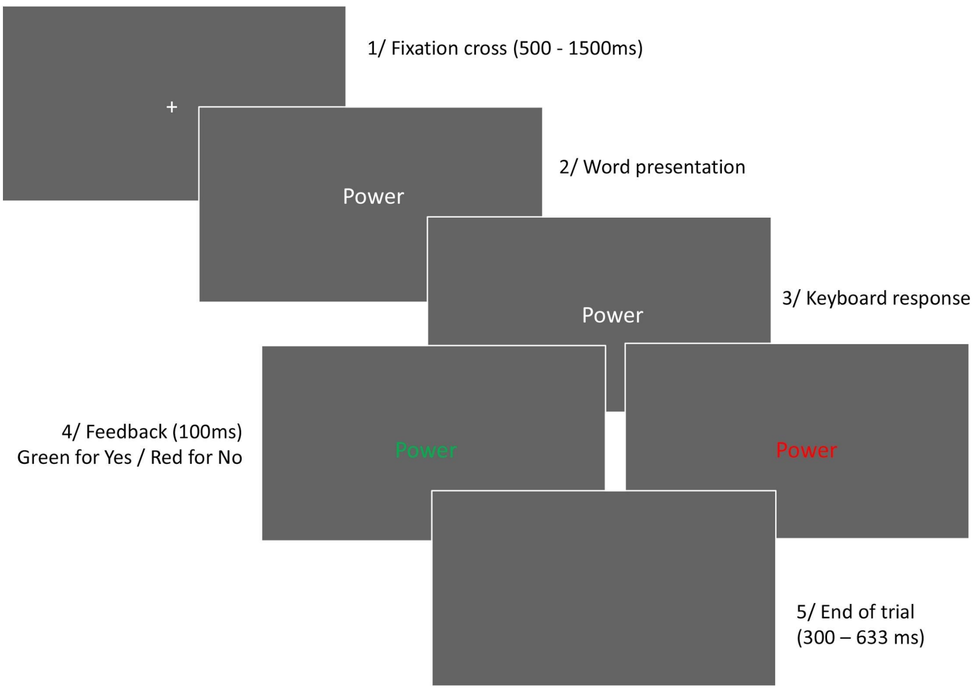
Based on these observations, a chronometry task was here designed in which participants were instructed to quickly make a decision about whether a word corresponded (or not) to their concept of leisure physical activity. Based on the working hypothesis that there is a link between response certainty and response time, the assumption here was that specific semantic maps and motivation profile could be traced by measuring motor reaction time profiles.

2.3.1 *Population, task and procedure*

After a 15-minute break, all 45 participants entered another silent and dark room for the second task that lasted approximately 4 minutes. Participants were seated in front of table on which was placed a screen and a 2-button response box. Once comfortable installed, each participant was instructed to place her/his index fingers on the two response buttons, placed on either side of the screen.

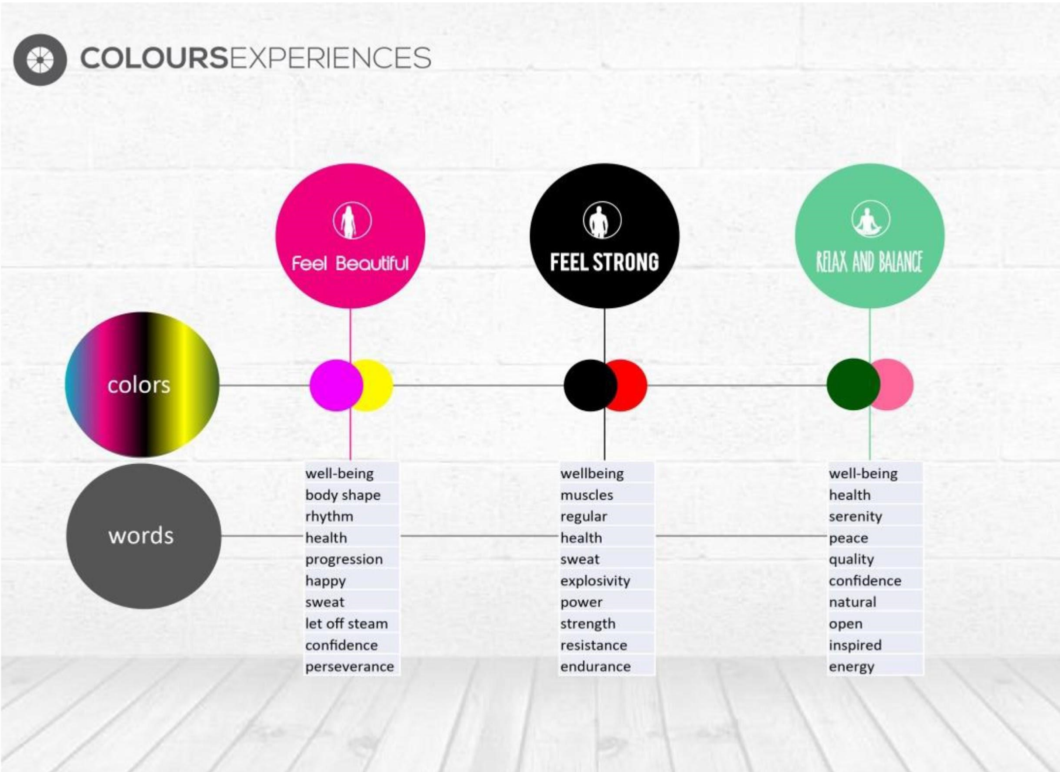
Each participant was instructed to imagine engaging in her/his preferred physical activity session - recalling the sensorial and affective experiences of a session that they particularly liked. Then, each participant was instructed to fixate the cross that appeared in the center of the screen and read the word that was presented. The task was to think whether the word corresponded to her/his image of what sports is, and to indicate yes or no by pressing the corresponding response button. The side on which was presented the yes and no buttons was counterbalanced across participants. To confirm the key press , the word turned green or red when the key press yes and no was selected, respectively (Figure 6). The colored word stayed on the screen for 0.5 s before the presentation of a grey screen that indicated the end of the trial. There was no possibility to correct. The response times taken to make the

Figure 6: Illustration of the experimental procedure used to determine word preference as a function of motivation profiles.



decision were measured (in ms) for each individual as a function of their motivation Profile.

Figure 7: Colors and word preferences obtained in tasks 1 and 2 as a function of motivation profiles. These combinations were used by the designers to construct motive-specific moodboards.



A total of 66 words were selected from a list of 250 words that was created on the basis of (1) nouns and verbs used in the questions of the PALMS questionnaire, and (2) nouns, adjectives and verbs extracted from publicities used in the sport industry. The sub-selection of the 66 words was defined by a group of 5 designers who had over 5-year professional experiences in the sports industry. A translation of a selection of these words is presented in Figure 7. These words were presented in a total randomized order, in the center of the screen, for a total trial duration of 3.1-6.5 s depending on the time taking by the participant to respond.

Stimuli display and response recordings were controlled using MATLAB 7.6.0. software. The response times to each word was first measured for each individual. Then, the words were ranked as a function of their corresponding response time and coded side. We considered here that the words receiving the shorter response times would be the most discriminant, as the participant decided quickly on the category in which they belonged. Hence, these were the words that were further analyzed. The top ranked 10 words were considered as least and most relevant, for the left (NO button) and the right (YES button) responses. These word lists are presented in Figure 4. A repeated measures ANOVA was conducted first on mean response times averaging across all words, with Profile (PSY; PHY; APP) as independent variable and Type (yes; no) as repeated variable. Then, a second repeated measures ANOVA was conducted on mean response times on the first 10 top ranked words only as a function of Profile and Ranking position. Independent analyses were conducted for most (yes button) and least (no button) relevant words. The alpha significance level was set to 0.05. Throughout these analyses, partial eta squares (2p) were calculated to report the effect sizes. Bonferroni-adjusted pairwise comparisons were used when required for the post-hoc analyses.

2.3.2 *Results and conclusion*

There was a significant effect of Profile on mean response times ($F(2,42) = 3.555$, $p = 0.037$, $2p = 0.145$) with PHY being significantly longer (1.643 s ± 0.74) to respond than APP (1.396 s ± .078) and PSY (1.384 s ± .068). There was an absence of Profile effect for the most relevant words ($F(2,42) = 1.126$, $p = 0.334$, $2p = 0.051$) and the least relevant words ($F(2,42) = 0.836$, $p = 0.441$, $2p = 0.038$), indicating that overall decision making was performed following a similar strategy in the PHY, APP and PSY groups.

In all profiles, the first ranked word was well-being. This was very systematic and was confirmed in 82% of our participants. The following ranked words were however profile specific. After ranking the words and taking into account only the 10 first ranked words of relevance, the Profile main group effect disappeared ($F(2,42) = 2.747$, $p = 0.076$, $2p = 0.116$). Participants responded on average in .957 s (+/- .057), 1.113 ms (+/- .062) and 1.129 ms (+/- .065) in the APP, PHY and PSY, respectively.

For the most relevant words, the main effect of Rank was significant ($F(2,42) = 5.032$, $p = 0.001$, $2p = 0.107$), with the first two words being selected faster than the words ranked 7-10. Response times to least relevant words were overall longer (1.650 ± .246 s) than the response times to the most relevant words (1.066 ± .104 s). For the least relevant words, the main effect of Rank was also significant ($F(2,42) = 5.032$, $p = 0.001$, $2p = 0.107$), with the first three words being selected faster than the words ranked 8-10. The Profile main group effect was not significant ($F(2,42) = 2.747$, $p = 0.076$, $2p = 0.116$) with response times of 1.278 ms (+/- .078), 1.427 ms (+/- .082) and 1.370 ms (+/- .065) in the APP, PHY and PSY, respectively. The lists of the 10 most relevant words and the two least relevant words for each profile are presented in Figure 7.

From the results obtained in tasks 1 and 2, specific words and color backgrounds were selected for the moodboards that were constructed by experienced designers and used in task 3 (see Figure 8). In the final section, we describe the use of thermal cameras to benchmark the quality of the moodboards against the emotional reactions that they triggered.

2.4 Task 3: Benchmarking designs with thermal responses

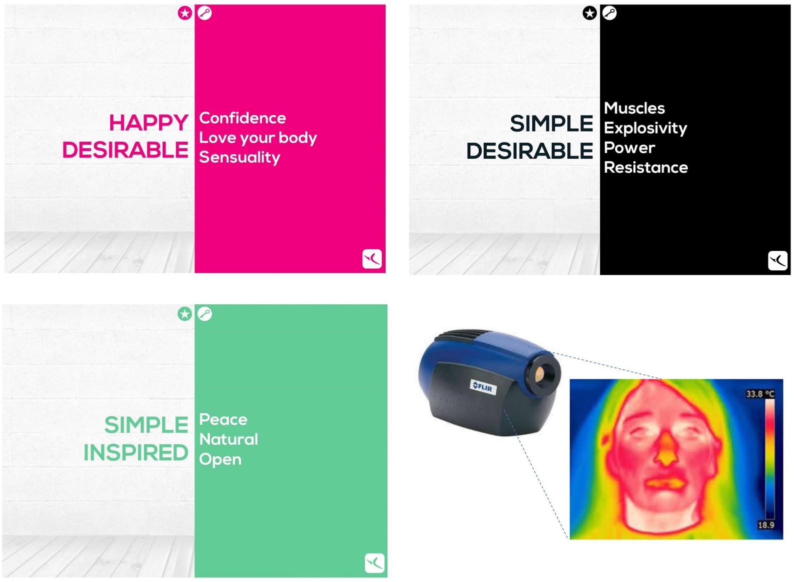
Body temperature can vary by a few degrees for both biological and psychological reasons. Indeed, someone can raise temperature when fighting a virus but can show cheeks that blush within seconds when feeling embarrassment (Porges, 2001; Skitzki et al., 2007). Many physiological consequences of emotional changes are slow phenomenon, taking over 5 seconds for full-blown responses (e.g., electrodermal activity). Hence, other measures like functional infrared imaging (fITI) are being preferred to measure the facial correlates of spontaneous emotional arousal. Current technological advancements allow measurements of emitted infrared heat by electronic thermal imaging (Ring, 2004) even when not observable by the human eye. It is the case that fITI harnesses the body's naturally emitted thermal irradiation and thus, enables cutaneous temperature recordings to be measured rapidly, ecologically, and contact free. In the present task, we used a high sensitive thermal infrared imaging system that is presented today as a promising method to study changes in human emotions.

The fITI technic remotely captures cutaneous surface thermal radiation that depends on cutaneous blood perfusion controlled by the autonomic nervous system (ANS) innervating the vessels that irrigate the skin (Ioannou et al., 2014). The vasomotion is regulated principally by sympathetic noradrenergic fibers, whose activation leads to vasoconstriction and, therefore, to a decrease in local temperature (Donadio et al., 2006; Westcott & Segal, 2013). Even if in its infancy, the use of thermal decoding has revealed a powerful means to characterize positive and negative reactions to external stimuli (Gulyaev et al., 1995; Merla & Romani, 2007). Indeed, greater thermal and dermal responses were reported in reaction to pictures with emotional compared to neutral contents (Kosonogov et al., 2017). Through the viewing of the scene of Alfred Hitchcock's movie "Psycho", Kistler (Kistler et al., 1998) reported temperature decreases of up to 2°C (at the fingertips) as a result of vasoconstriction. Similar decrease in thermal signals of the face were later reported in fear-conditioned individuals (Merla & Romani, 2007). Researchers from Japan studied joyful expressions in infants in which laughter was elicited during playing with a stranger. Significant increase in the nose temperature was observed 15–30 s after laughter onset. In the present study, we hypothesized that moodboards that were preferred should provoke a positive emotional reaction, which should in turn trigger an increase in thermal responses of the face.

2.4.1 *Population, task and procedure*

All 45 participants were invited to come back in the lab one month after the first session in order to participate in a second experimental session lasting approximately 30 minutes. Individually, participants were seated comfortably in front of a table on which was placed a screen, above which an infrared thermal imaging camera FLIR SC5000 (FLIR systems, USA) was mounted. The Research IR 4.0 software was used

Figure 8: Moodboards used in task 3, based on the eye-tracking and chronometry results obtained in studies 1 and 2.

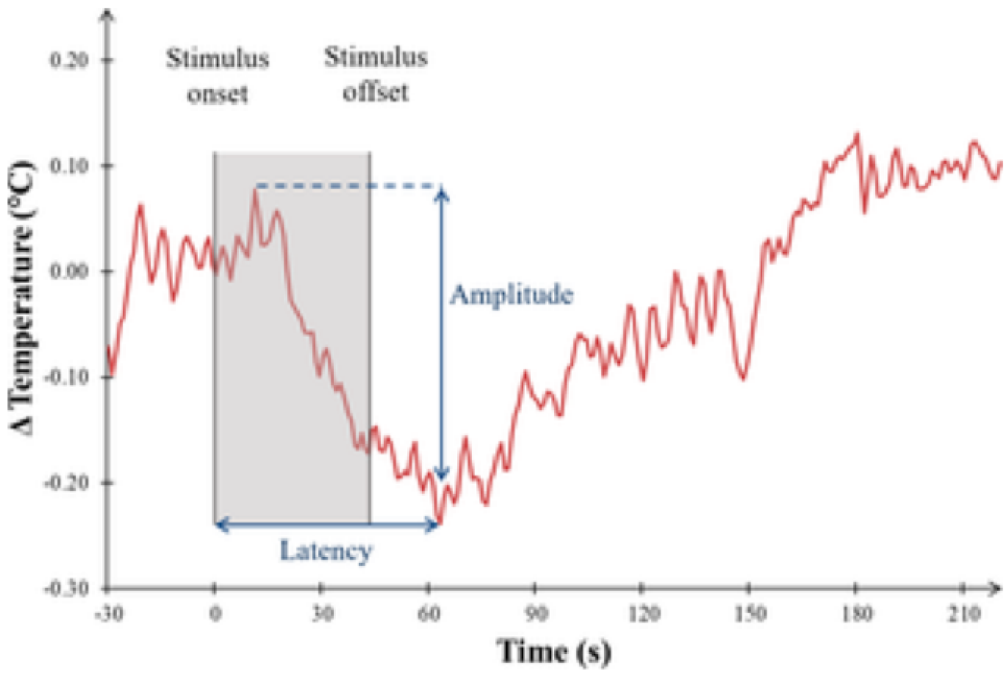


to measure temperature as a function of time at a 250 Hz frequency. The MATLAB software was used to record, filter and analyze the collected data.

At the start of the session, all participants were presented with a series of neutral pictures selected from the International Affective Picture System (IAPS; Lang, Bradley, Cuthbert, 2008; valence = 4.97 ± 1.15, and arousal = 2.91 ± 1.91). Following a semi-random order, 30 different moodboards (10 per profile) were presented with a viewing duration of 15 seconds. A grey screen was presented in between each moodboard for 5 s (see examples in Figure8). The participant's task was to look at each board and to imagine the fitness concept that was contained within the slide.

Data analyses were conducted post-collection on each individual trial. Thermal amplitudes were calculated and averaged across trials and participant. They were defined as the difference between the baseline level calculated during the first 60 seconds of presentation and the maximum peak found during the simulation phase. The latency was calculated as the difference between stimulus presentation and the same minimum. An illustrative example is presented in Figure 9.

Figure 9: A typical thermal response in an unpleasant trial.



2.4.2 *Results and discussion*

The results indicated that the PHY group demonstrated, on average, stronger increases in facial temperature (3.52 %) than the APP (0.74 %) and the PSY (0.23 %). Nevertheless, specific pattern of temperature change was observed as a function of motivation profile. Facial temperature changed in the APP individuals more when viewing APP moodboards (+5.04 %) than PSY (-0.88 %) and PHY moldboards (-3.87 %). Facial temperature changed in the PSY individuals more when viewing PSY moodboards (+2.89 %) than APP (+2.61 %) and PHY moldboards (+1.57 %). Facial temperature changed in the PHY individuals more when viewing PHY moodboards (+6.09 %) than APP (-8.59 %) and PSY moldboards (-1.44 %).

Over 54% of European adults are today considered as inactive, practicing less than 30 minutes of vigorous physical exercise per day. Hence, the ability to create effective and adaptive moodboards to trigger the intention to start exercising is thought as a potential key to help fight physical inactivity. Well selected illustrations can provide imaginary settings for a story-line but the task of creating impacting and adapted visuals is difficult due to the absence of a formal benchmarking approach for moodboard design (Gentes et al., 2015). Our findings indicated that eye-tracking could be used to guide the selection of color palettes. Indeed, the findings of study 1 indicated that the ranking for color patches was different as a function of motivation-profile. Hence, the duration of gaze fixation can be used to determine relevance; this feature was sensitive enough in the present setup to determine contrasting shades of color as a function of motivation-profile.

For adults aged 25-64, the recommended dose of physical activity for health benefits is 150 minutes per week of moderate- intensity aerobic activity like brisk walking (ACSM, 2009). Nevertheless, a large proportion of the population in the U.S. (Butcher et al., 2008) and in Europe (Armstrong & Welsman, 2006) are still insufficiently active and maintain a sedentary lifestyle. Hence, a line of innovation and development research has been initiated to promote the pleasure of physical activity using promotional material in public places. The scope is to post visuals throughout the community to trigger the hidden motivates and the dormant decisions to engage in physically more active lifestyles.

Emotions, play an adaptive coordination role, activating a set of responses physiological and behavioral, in order to deal fast with problems or opportunities (Keltner et al., 2014). Research indicates that anger is associated with the desire to change the situation and "move against" another person or obstacle by fighting, harming, or conquering it. Readiness appears not only expressively but also physiologically. Anger, for example, is linked to neural activation characteristics of approach motivation (Harmon-Jones & Sigelman, 2001) and, in some cases, changes in peripheral physiology that may prepare one to fight, such as increased blood flow to the hands (Ekman & Davidson, 1994).

In the context of leisure sports, we used a well-validated questionnaire to select individuals with different profiles of motivation to engage in an active lifestyle. We reported data indicating that the first saccade to a color patch is not discriminant and that, not surprisingly, bright reds catch the eye. Nevertheless, by measuring the total duration of viewing time across a series of presentation, we show that different colors are relevant to individuals as a function of their motivation profile (appearance: pink; psychological well-being: green; physical strength: black and red).

2.6 GENERAL CONCLUSIONS

Moodboards are abstract visual experiences that transmit a feeling of a design idea. There is to date no formal methodology for benchmarking moodboards. We present data suggesting that the combination of eye-tracking and chronometry may provide the means to use scientific-based knowledge to build impacting affective moodboards. Using novel thermal camera measurements, it was possible to show that greater temperature increases were triggered when individuals were presented with their corresponding moodboard. Future work will need to report whether the valence and arousal level of the emotional reaction measured with the fIRI technic predicts behavioral intention and decision.

2.6.1 *Acknowledgments*

Special thanks to Alexandre Abad and his team from the Sports LAB (DECATHLON, S.A.).

3

STUDY 2: PERCEIVED RESTORATION RESPONSES TO COLORED STREET VIEW IMAGES

Adapted from publication in: International Color Association, AIC 2021.

TITLE: Using color to promote restorative sidewalk experiences: an experimental study based on manipulated street view images

Authors: Lanqing GU, Adamantia BATISTATOU, Yvonne DELEVOYE-TURRELL, Jenny ROE, Martin KNOLL

3.1 INTRODUCTION

In the built environment, colors have been used in various situations and the psychological effects of colors include effects on happiness, relaxation, and arousal (Akers et al., 2012; Güneş & Olguntürk, 2020; Kutchma, 2003b). However, most of these studies looked at interior space; little research has focused on the psychological effects of colors in outdoor urban environments.

Walking can be restorative. This is the case when strolling through a lacking-greenery urban environment with historical elements and various architectural features and in such cases, walking experiences can be as good than walking in a natural environment (Karmanov & Hamel, 2008; Lindal & Hartig, 2013). Indeed, the term "restorative environments" relate to any space that offer the settings to facilitate recovery from mental fatigue and stress, i.e., any environment that elicit positive affective states. Attention Restoration Theory (ART) (Kaplan, 1992) posits the 4 properties of a restorative environment as following: being away (being mentally away from daily routine which leads to mental fatigue), fascination (being attracted by fascinating stimuli in environment that employ our involuntary attention), extent (the environment is large enough to form “a whole different world”) and compatibility (the actions required by the environment fit with an individual's inclinations). Being away and fascination were selected to be the metrics in this study.

Sidewalk ground surface plays an important role in the walking experience, as it has the direct, tactile contact with users. Its features could impact users' perception and behavior (Van Cauwenberg et al., 2016). However, no study has explored the effects of sidewalk ground color on mental well-being, even if colors have been extensively applied in transport projects to mark zones and convey information. We argue that there is a need to pay more attention in the use of color interventions (e.g., applying paint) in urban design to improve place quality, as it is more economical, feasible, and effective compared to other design approaches (e.g., urban vegetation).

In the present study, we aimed to use manipulated street view images to examine the impact of sidewalk ground color on perceived restorativeness and affective well-being in an urban street scene lacking natural greenery. We tested the effects of red, green, and blue, which are the most frequently applied colors in color psychology research. In previous studies, it was reported that red increased arousal (Wilms & Oberfeld, 2018a; Wilson, 1966), while green and blue were linked to increased relaxation and percevied levels of happiness, i.e., positive hedonic states (Bellizzi & Hite, 1992a; Wexner, 1954).

Our hypothesis was that colorful floor marking will be characterised by higher perceived positive affective states and restorativeness compared to that observed in environments without colorful floor marking (control condition). Given previous literature, three main hypotheses were formulated:

H1: Colorful sidewalks will trigger more positive perceived hedonic tone compared to control.

H2: Red sidewalk ground color will trigger higher arousal levels compared to blue, green and control.

H3: Green sidewalk ground color will trigger higher perceived restorativeness compared to all other colors and control.

3.2 METHODS

3.2.1 *Participants*

All participants were enrolled through online recruitment advertisement. Participants voluntarily joined the study and could stop on the online survey any time. Incomplete questionnaires were discarded. After reading the information sheet, each participant performed a color blind test to ensure that they could distinguish and correctly recognize the colors presented in the experiment. Finally, demographic data were collected (sex, age and familiarisation with the street that the study used).

All data collected from participants were anonymous. This protocol obtained an approval by the ethical committee of of Technisheche Universität Darmstadt (EK 36/2021). A total of 71 participants accessed the survey ; 5 individuals did not pass the color blind test and were excluded from the study. Among the 66 participants, 42 were females. The mean age was 26 (SD=4.605) and the age ranged from 19 to 36 years. One third of the participants (n= 23) had never been to Rheinstraße, whereas the others had varying degrees of familiarity with the street in question.

3.2.2 *Materials*

3.2.2.1 *Procedure*

All participants were required to do the online survey with a computer screen. They were first asked to standardize the screen settings regarding color, gamma, brightness, and contrast. After this, they were invited to perform the online color blind test. After this inclusion phase, participants responded to a series of questions that provide the means to evaluate their subjective mood state, information that was used to create the baseline. Following this, the participants were shown 8 street view images in a randomized order. They were asked to watch each image for at least 10 seconds to immerse themselves in the environment and then rate the street view image on perceived restorativeness and subjective mood state. Finally, participants were asked to provide information about gender, age, and familiarity with Rheinstrasse before being thanked for their time.

3.2.3 *Experimental Stimuli*

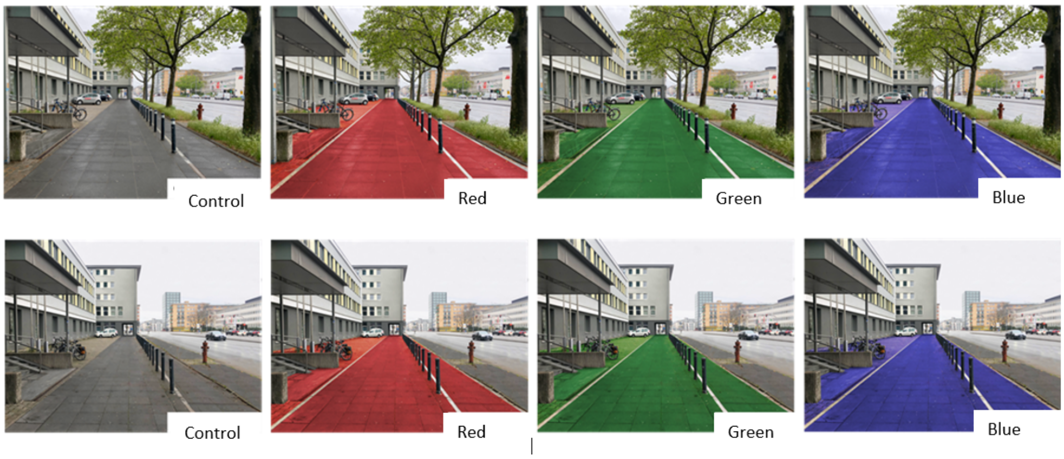
We used manipulated street view images to simulate a walking environment. The street view was selected from Rheinstrasse, (Darmstadt), which is a very large inner-city arterial street. Indeed, it includes: 4 lanes for cars, a tram and a bus corridor in the center, green buffers as well as cycle and pedestrian infrastructure. This arterial street was selected because Rheinstrasse is considered in urban architecture as a classic represent of what may be in the 21st century a typical arterial street in a medium size European city. The street view photo was taken on an overcast winter day. Major greenery was removed to create the image to be used as control condition.

Photoshop was used to create a total of eight different versions of the Rheinstrasse street. In the Urban environment, there were no green elements, only buildings. In the Nature environment, grass and trees were included. In both types of environments, a total of four design scenarios were tested. (1) no colors (control) (2) red color (255, 0, 0) (3) green color (0, 128, 0) and (4) blue color (0, 0, 255), which are additive primary colors in the RGB color model. The photo display was randomized between participants. See Figure10

3.2.4 *Measurements*

Subjective mood states measures comprised hedonic tone, arousal, and relaxation. The mood assessments were conducted before exposure to image stimuli and after watching each image to measure mood change. The statement for each mood item was rated on a 9-point Likert scale (from 1= “extremely disagree” to 9 = “extremely agree”). The three statements were: Hedonic tone: “I feel happy”; Arousal: “I feel energetic”; Relaxation: “I feel calm”. Perceived restorativeness was measured by using the Perceived Restorativeness Scale – short version (PRSscale - Berto, 2005). Two

Figure 10: Illustration of the eight color scenarios. Top row: Nature type with no color, red, green and blue sidewalks. Bottom row: Urban type with no color, red, green and blue sidewalks



statements corresponding to "fascination" and "being away", which are two restorative properties of the environment in the ART model. These two statements were rated on a 9-point Likert scale (from 1 = "extremely disagree" to 9 = "extremely agree"). It is to note that the statements were re-edited in the present study to adapt the question to the walking task (Fascination: "This place is fascinating and it is hard to be bored"; Being away: "Spending time here gives me a break from my day-to-day routine").

3.2.5 *Data Processing and Statistical Analyses*

Data processing and analysis were performed with both personal code and algorithms written in Python. Classic null-hypothesis significance tests were applied to reveal the impact of Color and Environment Type on user responses to the questionnaires. The results obtained in the eight Conditions (Urban Control, Grey Red, Grey Green, Grey Blue, Nature Control, Nature Red, Nature Green and Nature Blue) were contrasted using non-parametric tests as the variables were ordinal data, and the normality conditions were not met. The non-parametric Friedman test was applied to confirm significant Condition differences. The probability level was set to .05 for test interpretation.

3.3 RESULTS

Results for the mood scales are presented before presenting the findings of the perceived restorativeness.

3.3.1 *Perceived hedonic tone*

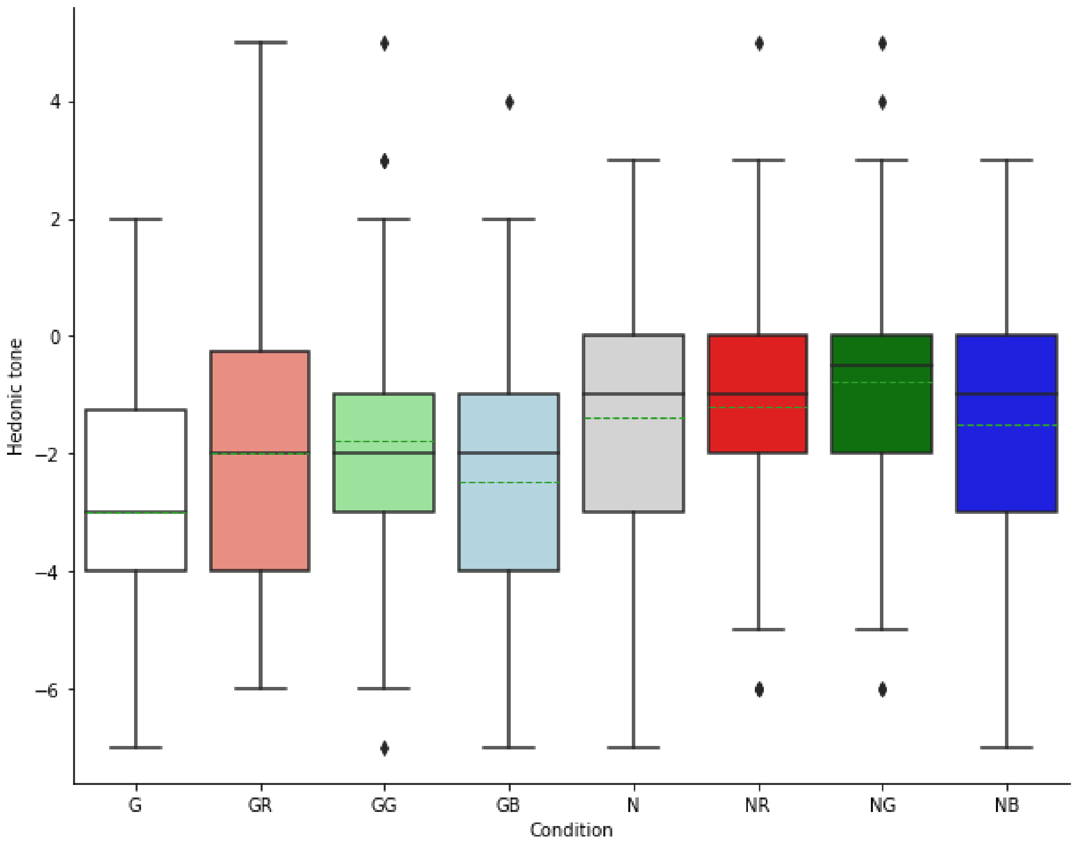
The non-parametric Friedman test revealed a main effect of Condition on Hedonic Tone, $X^2(7) = 112.44$, $p < .001$, with lower scores in Urban (Mdn = -3, IQR = 2.75) than Urban Red (Mdn = -2, IQR = 3.75), Urban Green (Mdn = -2, IQR = 2), Urban Blue (Mdn = -2, IQR =3). These values were smaller than those seen in the nature enfironments, with Nature Green (Mdn = -0.5, IQR = 2) being greater than Nature (Mdn= -1, IQR = 3), Nature Red (Mdn= -1, IQR = 2) and Nature Blue (Mdn = -1, IQR = 3). Results are presented in figure 11.

The Conover's post hoc test confirmed significant differences between Urban Control and Nature Control ($p < .001$). There were significant differences in the Urban environments between Control and Red ($p < .001$), Control and Green ($p < .001$) as well as Green and Blue ($p = .006$). The differences were also significant in the Nature environments between Control and Green ($p = .006$), Green and Red ($p = .02$) as well as Green and Blue ($p = .002$).

3.3.2 *Perceived hedonic arousal*

The non-parametric Friedman test revealed a main effect of Conditions on Arousal, $X^2(7) = 134.91$, $p < .001$, with lower scores in Urban (Mdn = -3, IQR = 3.75) than Urban Red (Mdn = 0, IQR = 3), Urban Green (Mdn = -1, IQR = 3.75), Urban Blue (Mdn = -1, IQR = 4), Nature (Mdn= -1, IQR = 3), Nature Red (Mdn= 0, IQR = 1),

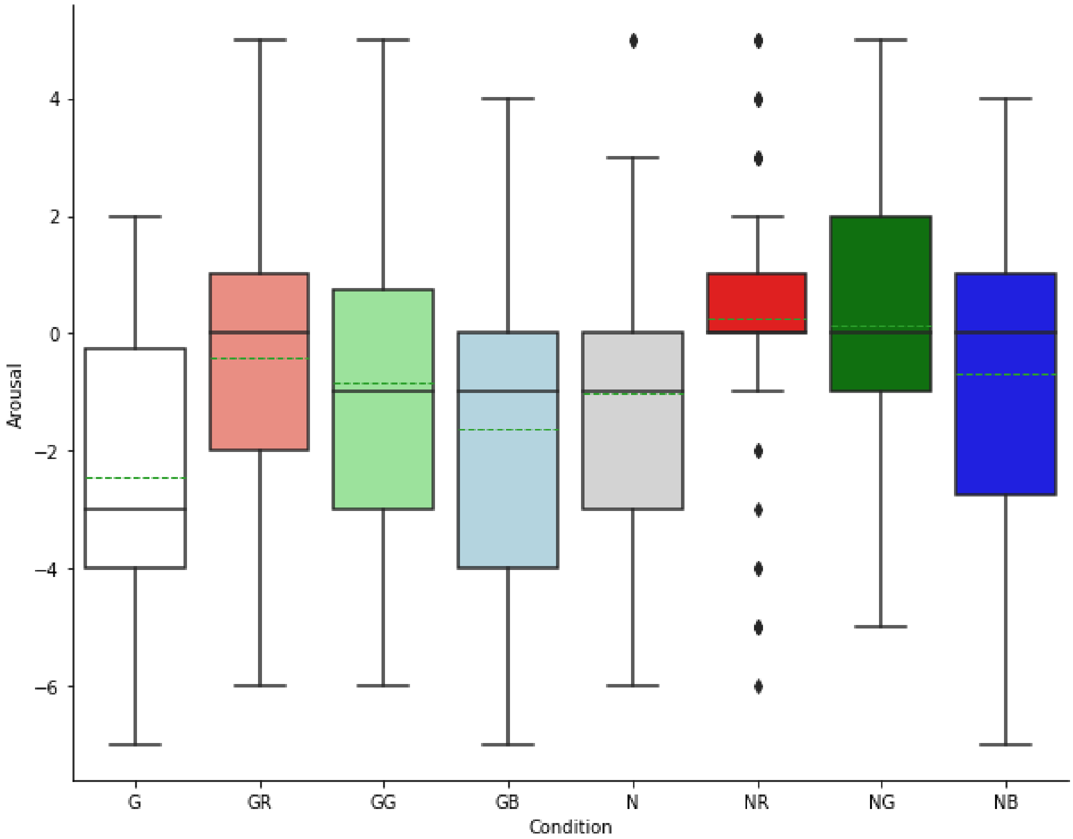
Figure 11: Bar charts illustrating the effect of Conditions on the mean changes in perceived Hedonic Tone. U = Urban ; UG = Urban Green ; UR = Urban Red; UB= Urban Blue ; N = Nature ; NG = Nature Green ; NR =Nature Red; NB= Nature Blue.



Nature Green (Mdn = 0, IQR = 3) and Nature Blue (Mdn = 0, IQR = 3.75). Results are presented in figure 12

The Conover's post hoc test confirmed significant differences in the Urban environments between Control and Red ($p < .001$), Control and Green ($p < .001$), Control and Blue ($p = .01$), Red and Blue ($p < .001$) as well as Red and Green ($p = .02$). The differences were also significant in the nature environments between Control and Red ($p < .001$), Control and Green ($p < .001$), Red and Blue ($p < .001$) as well as Blue and Green ($p = .001$).

Figure 12: Bar charts illustrating the impact of Conditions on the mean changes in perceived Hedonic Arousal. U = Urban ; UG = Urban Green ; UR = Urban Red; UB= Urban Blue ; N = Nature ; NG = Nature Green ; NR =Nature Red; NB= Nature Blue.

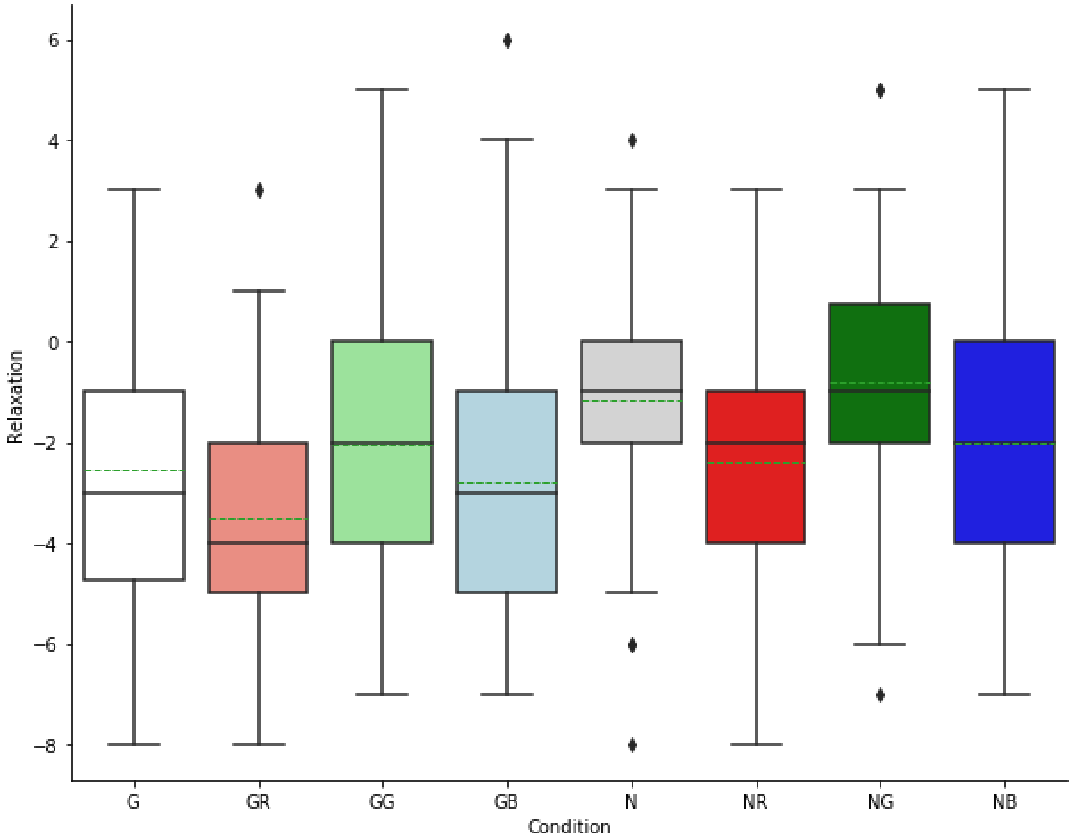


3.3.3 *Perceived relaxation*

The non-parametric Friedman test revealed a main effect of Conditions on Relaxation, $X^2(7) = 109.6$, $p < .001$, with lower scores in Urban Red (Mdn = -4, IQR = 3) than Urban (Mdn = -3, IQR = 3.75), Urban Green (Mdn = -2, IQR = 4), Urban Blue (Mdn = -3, IQR = 4), Nature (Mdn= -1, IQR = 2), Nature Red (Mdn= -2, IQR = 3), Nature Green (Mdn = -1, IQR = 2.75) and Nature Blue (Mdn = -2, IQR = 4). Results are presented in figure 13

The Conover's post hoc test confirmed significant differences between Urban Control and Nature Control ($p < .001$). There were also significant differences in the Urban environments between Red and Control ($p = .002$), Red and Green ($p < .001$)

Figure 13: Bar charts illustrating the impact of Conditions on the mean changes in perceived Relaxation. U = Urban ; UG = Urban Green ; UR = Urban Red; UB= Urban Blue; N = Nature ; NG = Nature Green ; NR =Nature Red; NB= Nature Blue.



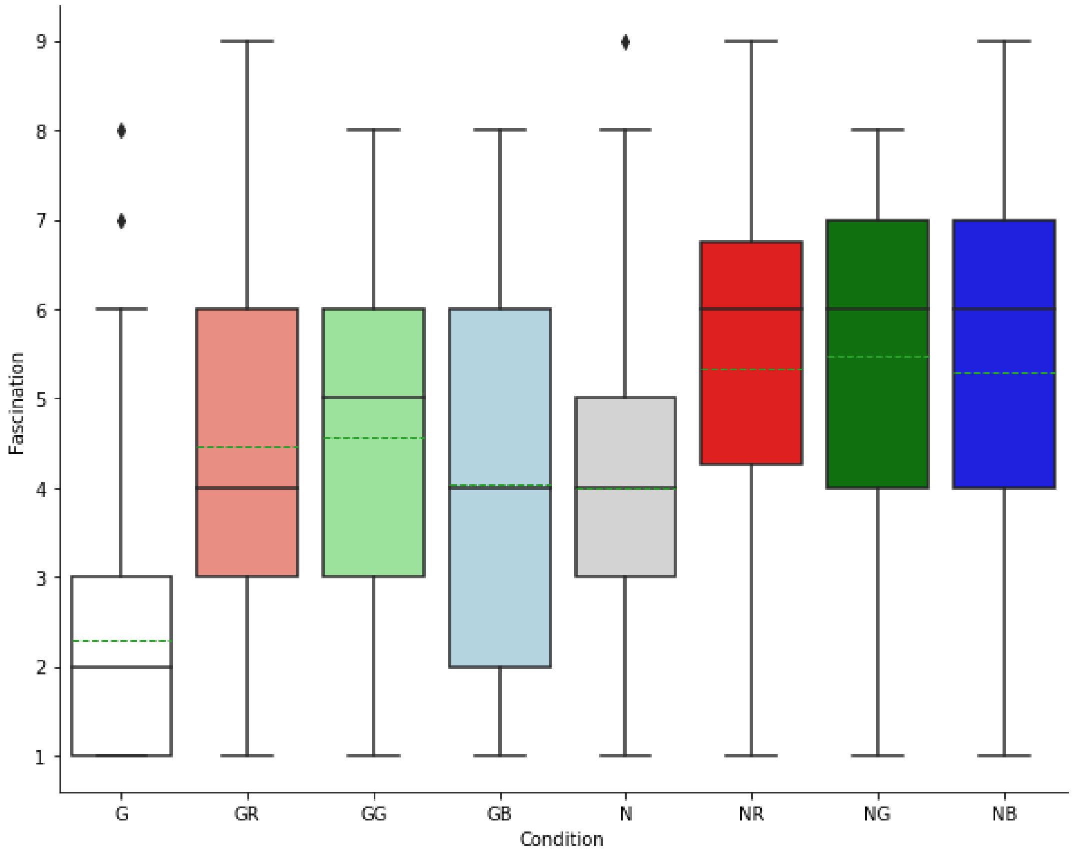
as well as Red and Blue (p = .01). The differences were also significant in the Nature environments between Control and Red (p < .001), Control and Blue (p = .02), Green and Red (p < .001) as well as Green and Blue (p = .001).

3.3.4 *The feeling of Fascination*

The non-parametric Friedman test revealed a main effect of Conditions on Fascination, $X^2(7) = 146.7$, $p < .001$, with lower scores in Urban (Mdn = 2, IQR = 2) than Urban Red (Mdn = 4, IQR = 3), Urban Green (Mdn = 5, IQR = 3), Urban Blue (Mdn = 4, IQR = 4), Nature (Mdn= 4, IQR = 2), Nature Red (Mdn= 6, IQR = 2.5), Nature

Green (Mdn = 6, IQR = 3) and Nature Blue (Mdn = 6, IQR = 3). Results are presented in figure 14

Figure 14: Bar charts illustrating the impact of Conditions on the mean changes in perceived Fascination. U = Urban ; UG = Urban Green ; UR = Urban Red; UB= Urban Blue ; N = Nature ; NG = Nature Green ; NR =Nature Red; NB= Nature Blue.

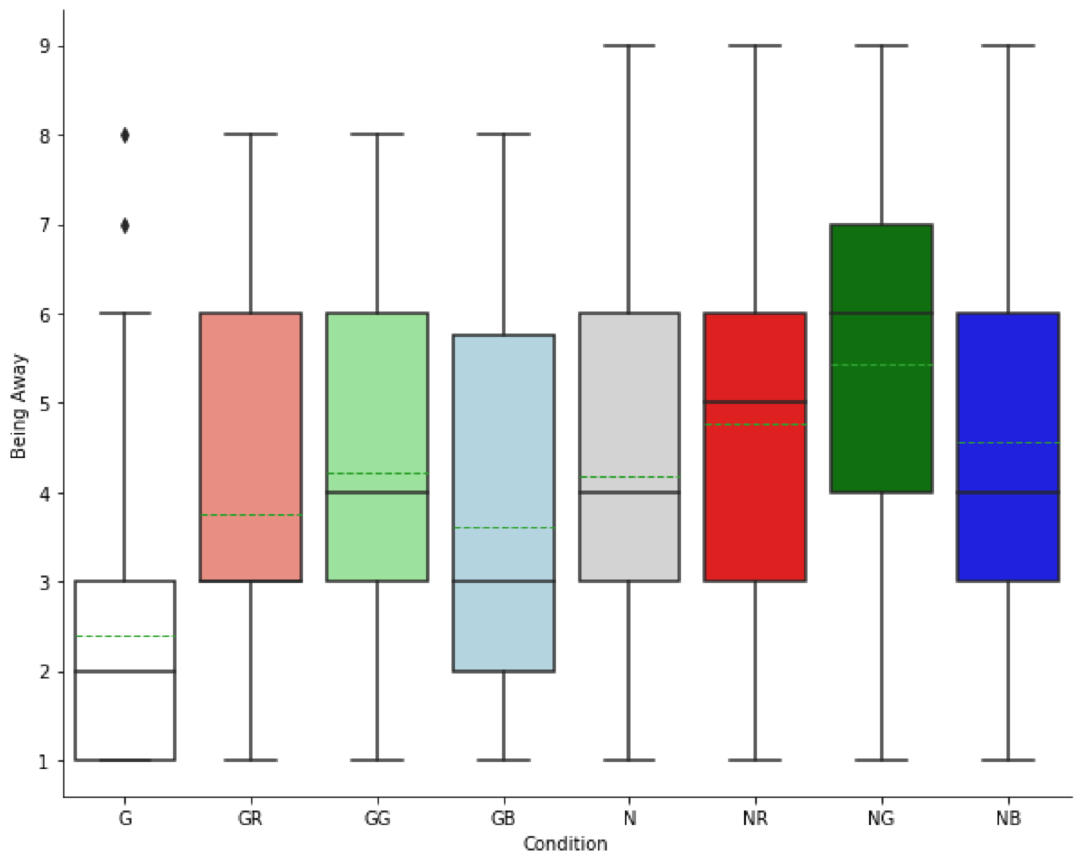


The Conover's post hoc test confirmed significant differences in the Urban environments between Control and each color ($p < .001$). The differences were also significant in the Nature environments between Control and each color ($p < .001$). There were significant differences between Grey Control and Nature Control ($p < .001$).

3.3.5 *The feeling of Being Away*

The non-parametric Friedman test revealed a main effect of Conditions for the feeling of Being Away, $X^2(7) = 138.53$, $p < .001$, with lower scores in Urban (Mdn = 2, IQR = 2) than Urban Red (Mdn = 3, IQR = 3), Urban Green (Mdn = 4, IQR = 3), Urban Blue (Mdn = 3, IQR = 3.75), Nature (Mdn= 4, IQR = 3), Nature Red (Mdn= 5, IQR = 3), Nature Green (Mdn = 6, IQR = 3) and Nature Blue (Mdn = 4, IQR = 3). Results are presented in figure 15

Figure 15: Bar charts illustrating the impact of Conditions on the mean changes in the feeling of Being Away. U = Urban ; UG = Urban Green ; UR = Urban Red; UB= Urban Blue ; N = Nature ; NG = Nature Green ; NR =Nature Red; NB= Nature Blue.



The Conover's post hoc test confirmed significant differences between Grey Control and Nature Control ($p < .001$). There were significant differences in the Urban environments between Control and Red ($p < .001$), Control and Green ($p < .001$), Control and Blue ($p = .002$) as well as Green and Blue ($p = .02$). The differences were also significant in the Nature environments between Green and Control ($p < .001$), Green and Red ($p = .04$) as well as Green and Blue ($p = .01$).

3.4 DISCUSSION

The objective of the present study aimed to use manipulated street view images to examine the impact of sidewalk ground color on perceived restorativeness and affective states. Overall, we report that color intervention had a positive impact on the perceived affective states and perceived restoration of people. These results are consistent with previous literature and confirm the possibility of using online studies to test design colors before implementation in the real world.

Firstly, our results confirmed the positive effects of colorful interventions on positive perceived hedonic tone responses. This confirms H1. All three colors had a main effect on perceived improvement of the urban space in the urban and natural environments. Red and green performed better than blue. The color green had more power to transform the space into the urban setting compared to the red which had better results in the natural environment.

Secondly, our results confirmed the positive effects of colorful interventions on perceived arousal responses, confirming H3. All the colors had a significant effect of higher arousal in the urban setting and natural environments. The results, confirmed partially our second hypothesis as red scored higher arousal levels, in the urban and in the natural setting, compared to control and to the blue intervention but not compared to the green intervention. The red intervention had a more powerful effect in in the urban setting compared to other colors in the urban setting. The results are reaffirming the association of red environment with high arousal (Wilms & Oberfeld, 2018a).

The overall, findings state that colors enhance perceived restoration when they are displayed in the ground floor of a public space.

The findings regarding perceived relaxation state a lower score for red color intervention in the urban setting compared to the rest of the interventions. Green color in the gray setting had significant better scores compared to red color. In the nature setting the green color intervention had better score compared to red and blue colors. Overall, green color had significant more perceived relaxation scores when it was used for enhancing the natural setting than when it was used to enhance the urban setting.

Regarding fascination findings state a lower score for urban control setting compared to the rest of the conditions. In the urban and in the nature setting, all colors had significantly enhanced fascination compared to the no color intervention condition. With nature colored interventions to have more fascination power compared to all colored interventions in the urban setting.

For Being Away, the urban setting had lower scores compared to the rest of the conditions. In the urban setting all colorful interventions succeed to upgrade the being away feeling with better results for the green intervention compared to the blue one. In the nature setting the green color intervention had better results compared to the rest of the conditions. All colors had more significant effect when presenting in the nature setting compared to the urban one.

3.5 LIMITATIONS

There are limitations in this study. First, we used static images as visual stimuli to have the participants simulate the walking experience, which might be immersion-deficient. Although we added a 10-second countdown timer to the images, it was still too short to elicit the proper psychological response. In the future, street view videos with replaced sidewalk ground colors or interventions in real sidewalk environments can be used for improving ecological validity.

Second, in this study only the effects of the three intervention colors were tested. Studies have shown that hue, saturation, and brightness of color have an impact on emotion (Gao et al., 2007). Future studies can focus on how these attributes of various colors influence psychological response in urban outdoor space.

Third, practices with color usually have a combination of colors as well as graphic design, all of which can also influence perception. Studies have been conducted to explore the effects of color combinations on psychological responses (Deng et al., 2010). Future research could attempt to combine color psychology and graphic design to explore the effects of their interaction on affective responses, thus providing more detailed design bases for urban design. Finally, the effects of personal color preferences and cultural background on affective response were not considered in this study. Studies have shown that demographic geographic location, gender, cultural background, and color preference can all influence affective response (Naz & Helen, 2004).

Future research could explore the difference in emotional response of colors in outdoor environments among people with different cultural backgrounds. Studies should consider also the question of color preferences to examine whether there is consistency in the psychological responses of different populations to color design in urban spaces.

3.6 CONCLUSION

This study reveals that in the urban street color interventions can impact the perceived affective states of the pedestrians. Color intervention enhanced the positive experience of the pedestrians. The colors red and green had stronger positive effects compared to blue color. Also, the red color stimulated the perceived energy of the pedestrians.

Finally, colors had an impact on the perceived restorative aspect of the street when displayed on the sidewalk. The red color in the urban setting had negative effect on the perceived relaxation from the users, while the green color had strong effects on creating positive perceived relaxation. Also, all colors had successfully enhanced the perceived fascination and the feeling of being away with stronger effects when used on the nature setting than on the urban setting. The findings suggest that ground color interventions have the potential to be a further effective means of optimizing urban environmental qualities related to mental well-being, in addition to inserting much-needed natural green, as a complementing, cost-effective, and temporary response to streets that lack trees. The study provides a preliminary empirical basis for future urban outdoor space design.

4

STUDY 3: VIRTUAL REALITY FOR USER TESTING

Submitted to: Frontiers

TITLE: Virtual Reality and Psychological Testing: An Innovative Method to Evaluate the Impact of Color Visual Environments on Spontaneous Walking, Gaze and Emotion

Authors: Adamantia BATISTATOU, Florentin VANDEVILLE, Yvonne DELEVOYE-TURRELL

4.1 INTRODUCTION

Measuring human experiences in natural settings is complicated. In architecture, virtual reality (VR) is often used as a tool to reproduce a pre-existing design found in urban spaces. Recently, VR has also been suggested as a tool to select the best implementation of a future urban design, applying immersive user testing (Heydarian et al., 2015). This method of prospective evaluation in urban planning is low cost and allows the assessment of human user experiences in a controlled environment. Questions such as the influence of landmarks on way-finding (Bruns & Chamberlain, 2019), the influence of implementing green elements on perceived stress (Hian et al., 2021) and the impact of crossroads on pedestrian safety (Deb et al., 2017) are a few examples of such VR testing applications. In the present paper, we describe a tutorial on how immersive new-age VR technology and wearable sensors can be used as an innovative method in psychological sciences. In addition to classic questionnaires and wearable wrist band, we integrated an eye-tracking system within the HTC Vive helmet to obtain quantification of gaze behavior. The case study reported here will illustrate how the VR methodology can solve one of today's challenges of testing urban design scenarios to promote pleasurable experiences during pedestrian behavior.

4.1.1 *Colors impact the walking experience*

A variety of direct and indirect environmental factors have been shown to impact pedestrian experience (Wood et al., 2010; Wunderlich & Filipa, 2008). Direct elements are those having a direct influence on the action of walking, such as car traffic, pedestrian density, and sidewalk configurations (Muraleetharan et al., 2004; Zakaria & Ujang, 2015). The indirect elements impact pedestrian experiences in an unconscious way such as nature, sounds and odors (Tyrväinen et al., 2014; Ulrich et al., 1991). Under these terms, color and colorful designs are considered as indirect elements. Even more so than sound, colors are difficult to manipulate in the natural environment as they depend on the lighting conditions and shadows. Controlled experiments in color psychology is thus very limited in number and as such, we decided to focus this tutorial on how to use new tech to test the impact of colorful designs on human experience.

Color is an essential visual factor of the environment (Jalil et al., 2012). Empirical observations have reported the impact that colors may have on walking perception and behavior. For example, runners with red T-shirts were perceived as running faster than those wearing blue T-shirts (Mentzel et al., 2019). Another study observed that people walked faster when presented with red stimuli compared to trials for which blue stimuli were used (Meier et al., 2012). In art, color walks have for decades been described as a key solutions to improve walking experiences through the city (Evans, 2019) but little quantification has been reported. A few studies in environmental psychology have recently used virtual reality techniques to reveal longer fixation-time for nature scenes versus urban cities (Valtchanov & Ellard, 2015a). Our objective here was to report an innovating VR system that is implemented with eye-tracking and wearable sensors to gain a global psycho-physiological evaluation of how colorful designs may influence spontaneous walking speed, perceived stress, physiological emotional states and eye gaze strategies in a controlled environment.

4.1.2 *Spontaneous walking tempo*

The Spontaneous Motor Tempo (SMT) is defined as an automatic regular sequence of movements corresponding to the preferred and natural rhythm at which an individual decides to move (Fraisse, 1982). SMT is naturally observed in daily activities, such as clapping and walking (Rose et al., 2020) and has been associated to the pace for which movement production is the easiest, providing the most pleasure (Delevoye-Turrell et al., 2014). SMT is thought to be associated directly to the physiological effects that body movement provides. Indeed, SMT is a value that can capture the daily rhythm of people's lives and reveals how calm or hurried one's walking behavior is (Bornstein & Bornstein, 1976).

Walking speed in the urban space has been linked to stress. Environmental elements of the urban setting can cause a feeling of anxiety or alertness that triggers an increase in walking pace. Research has shown that elements such as light dimming and traffic noise can make walkers speed up, suggesting an increase in stress under busy urban settings (Franěk et al., 2018; Pedersen & Johansson, 2018). On the other hand, vegetation lead walkers unconsciously to slow down (Franěk, 2013). Indeed, human perception studies have reported that red impacts a walker's perception of time, perceived speed (Mentzel et al., 2019) and influences walking speed (Meier et al., 2012). However, these studies used simple line colors only.

In the present study, we assessed the impact of colorful lines and designs by manipulating the presence, color and size of floor-marking. The SMT was calculated using the accelerometer data contained within the hand-held VR controllers. Mean SMT was used as an indicator of alertness and of interest as it coded the time spent exploring a color walk.

4.1.3 *Gaze behavior*

Eye gaze patterns reveal what a person is looking at by characterising active exploration and passive detection, which are key processes when trying to understand human-environment interaction (Colombo, 2001). Gaze behavior is characterised by eye blink frequency, gaze direction and fixation time.

Blinking is the involuntary reflex of opening and closing the eyes (Volkmann et al., 1982). Blink rate varies systematically with specific behaviors such as reading, talking and video watching (Fukuda, 1994; Himebaugh et al., 2009). This is typically attributed to variations in cognitive load (Orchard & Stern, 1991). Despite evidence for some systematic variation with dopamine level, blinking is universally regarded as epiphenomenal, rather than functional. Much more research has however been conducted on gaze direction and eye-fixations, which reveals what is being looked at, across time (Chevalier et al., 2010): the sky, the ground or a specific Area Of Interest (AOI).

Gaze direction in the urban space has been linked to "journey fixation". During free walk, participants with normal vision direct their gaze primarily straight ahead targeting a goal, whereas individuals with impaired vision direct their gaze downwards, i.e., towards the edge-lines and the boundaries between walls (Turano et al., 2001). Furthermore, studies have reported the importance that environmental urban elements may play on gaze direction. For example, the complexity of the surface (Matthis et al., 2018) as well as the density of circulation (Trefzger et al., 2018) modulate systematically gaze direction.

Changes in fixation time is predicted in the urban space by the levels of interest given to an object or to an area of the environment by the walkers. Environmental elements placed in an urban setting may increase alertness and increase fixation duration, which suggests that the user is focusing attention on meaningful elements (Leveque et al., 2020). Research has also shown that elements such as crossroads and traffic lights increase fixation time (Biassoni et al., 2018; Fotios et al., 2014) . On the other hand, grass (Egorov et al., 2017a), and nature scenes (Ward Thompson et al., 2012) lead walkers to decrease the number of fixation points. Nevertheless, it is unclear whether these effects are due to the nature per se or to the colors. Indeed, in the field of cognitive psychology, perceptual studies have reported that people scored more fixations in counts and in duration when presented with their preferred colors, which sometimes included the color green (Lee et al., n.d.).

In the present study, we questioned how colorful designs in the urban environment could influence eye gaze strategies. Using a virtual reality headset with an integrated SMI eye-tracker, we report the number of blinks per minute, the fixation durations on pre-defined AOIs as well as the overall direction of gaze as a function of the colors presented in the VR environment.

4.1.4 *Affective states*

Affect is a psycho-physiological response that codes the level of interaction of a human with the environment. It describes a broad term of feelings that a person can have, consciously or unconsciously, towards an event or a stimuli (Batson et al., 1992b). Affects have two principal dimensions the valence and the arousal. The affective valence characterizes the perceived quality of the stimuli as pleasant or unpleasant (Russel, 1989). The affective arousal indicates the physiological levels of activation associated to the event at a given moment. In cognitive psychology, the valence is mainly quantified through self-reported questionnaires, whereas arousal can be assessed both subjectively and objectively, with the use of an equipment that measures the activation of the sympathetic nervous system (Wang et al., 2018). The combination of declarative and objective measurements is recommended today in the affective field of sciences for a better description of a user's affective state (Kondo et al., 2018a).

Changes in arousal have been linked to stress and many studies have reported the negative impact of urban elements can increase alertness on perceived and physiological arousal. Elements such as crowd density (Engel et al., 1997; Fleming et al., 1987), urban noise (Münzel et al., 2018), and high building facades (Kalantari

& Shepley, 2020) increase arousal levels. On the other hand, vegetation (Egorov et al., 2017a) and nature scenes (Ward Thompson et al., 2012) lead walkers to experience lower levels of arousal. In color psychology, studies have suggested that red triggers a significant increase whereas green decreases perceived and physiological arousal(Kutchma, 2014), which may indicate the power of colors to modulate stress levels.

Valence is associated to pleasantness. Urban environments such as traffic (Coensel et al., 2011) and build spaces (Berg et al., 2003; Wilkie & Stavridou, 2013; Özgüner & Kendle, 2006) cause less positive perceived affective states and can negatively impact pleasantness of walking. On the other hand, vegetation (Egorov et al., 2017a), integrated urban vegetation (White & Gatersleben, 2011), walking in the forest (Hartig & Staats, 2006), and physical exercise in natural environments (Focht, 2009) lead to positive experiences. In color psychology, studies have shown that blue and green colors are linked to more positive affective states than other colors (Kaya & Epps, 2004; Savavibool et al., 2018).

4.1.5 *Virtual Reality to confirm effects of color designs*

These empirical observations have mainly been obtained through declarative questionnaires. More recently, wearable watches have been used to quantify changes in heart rate and number of steps. But the number of case studies remain limited. Furthermore, no report to date has been able to report the impact of color designs on gaze behavior. Finally, without the possibility to contrast color and color design interventions against a neutral condition, the effects are limited in their reliability and generalizability. As a consequence, we engaged in the development of a virtual reality (VR) method, which would provide the means to assess in a controlled situation whether nature and colors in the urban environment impact the arousal and the perceived pleasantness of walking. Valence was self-reported, while arousal was quantified trough both self report and objective measures. The physiological arousal was quantified through heart rate (HR) measurements (Kondo et al., 2018a). Heart rate variability (HRV) was used to quantify stress levels (Ulrich et al., 1991).

Our hypothesis was that colorful floor marking comparing to the environment without colorful floor marking will correlate with more positive affect, lower physiological and cognitive stress. Given previous literature, four main hypotheses were formulated:

H1. A replication of Franek's 2013 findings was expected, such that speed of spontaneous walking would be greater in urban scenes than in nature scenes. Colorful designs but not color lines would have the power to reduce the speed of walking and especially in the urban scenes for which the greyness encourages brisk walking.

H2. Gaze in the urban space is rarely directed straight a head (von Stülpnagel, 2020). In more clouted environments as it is the case in urban settings, gaze orientation is directed towards the ground in order to detect possible obstacles (Van Cauwenberg et al., 2016). Hence, we expected gaze to be oriented more towards the ground when viewing urban scenes compared to nature scenes. Such behavior should be amplified with the presence of floor markings in both types of scenes. A replication of Valtchanov and Ellard (2015)'s (Valtchanov & Ellard, 2015b) findings was also expected, such that the number of fixations would be greater when viewing urban scenes compared to nature scenes. Colorful designs should increase the number of fixations because of the curiosity to discover the patterns.

H3. Blink rates were hypothesized to be lower when viewing nature scenes compared to urban scenes, given that (1) Green environments are believed to reduce stress and restore attention while (2) urban scenes are believed to be stressful and result in greater cognitive load (Berman et al., 2008; Valtchanov et al., 2010).

H4. Nature scenes were finally hypothesized to be self-rated as more pleasant than urban scenes, replicating previous findings in the restorative effects of nature literature (Valtchanov et al., 2010). In addition, we predicted that physiological responses would provide objective evidence of changes in affective states. Hence, heart rate variability should be lower when walking through urban scenes than nature scenes.

Colorful designs should increase mean heart rate variability especially for urban scenes, demonstrating the role played by colors in the restorative power of nature.

4.2 METHODS

4.2.1 *Participants*

Healthy adults were recruited for the present study from among the corpus of University of Lille staff and students. Participants had normal to corrected-to-normal vision, and did not present motor dysfunction or neurological/psychiatric disorders. After reading an information sheet, each participant answered a short questionnaire to verify that they could distinguish and correctly recognize the colors presented in the experiment. At this point, each participant was invited to provide written informed consent and demographic data were collected (sex, age, and VR expertise). This protocol obtained a favorable review by the ethical committee of the University of Lille (2019-328-S68) and is registered by the CNIL for good management of human personal data (GED UnivLilleN1-201816).

The sample size required for the critical statistical test of each research hypothesis was calculated using GPower (version 3.0.10) as proposed by Faul et al. (2007)(Faul et al., 2007). The behavior results of Chrisinger and King (2018) (Chrisinger & King, 2018b) were used as group parameters. The alpha of 0.05 and the power level of 0.8 were applied for the power analysis as the standard parameters levels recommended by Cohen (1990). The power analysis indicated that 32 participants would be required. Accordingly, a sample of 35 individuals (16 males, 19 females, mean=23.59 ± SD=8.79 age: 18-51 years) was recruited to account for possible technical failure.

Figure 16: Picture of a typical participant performing the experiment that lasted approximately 60 minutes with frequent breaks to limit nausea.

4.2.2 *Materials*

4.2.2.1 *Task and visual environments*

The participant's task was to walk and discover a virtual replication of the University campus. She/he was to follow a pathway that appeared in front of her/him. Depending on the conditions, the university campus displayed buildings (Urban environment) or buildings with trees and large grass patches (Nature environment). The path to follow could be a white line, or color-lines. Finally, colorful designs could be displayed upon the path. Hence, each participant discovered a total of six different versions of the University Campus that were presented in independent blocks. During the VR task, participants were asked to stand on a textured mat to help maintain body stability during the walking on the spot task (Figure 16). Hence, at the start of the session, participants were invited to take their shoes off.

Unity code was used to create a total of six different versions of the University campus. In the Urban environment, there were no green elements, only buildings. In the Nature environment, grass and trees were included using different shades of green and natural colors. In both types of environments, a total of three design scenarios were tested. (1) no colour floor marking (control); (2) a simple line crossing the campus in three RGB colours (red, blue or green); (3) a series of RGB colours embedded within playful designs. The position and size of the designs were randomized between participants. Illustrations of the VR environments are provided in Figure 17.

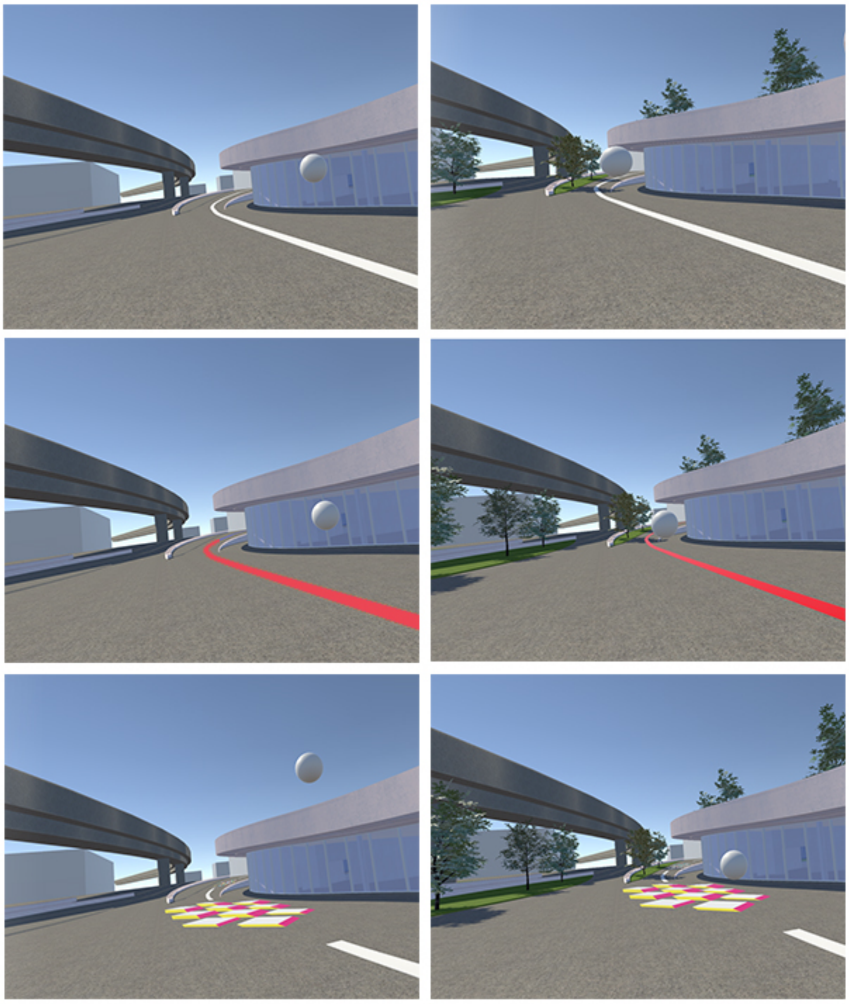
4.2.2.2 *Virtual Reality system and eye tracking*

The virtual reality HTC Vive was used. The light-weight headset displayed visual environments with a resolution of 1080 x 1200 pixels per eye for a 110° field of view. The refreshing rate was 90 Hz. The HTC Vive headset was implemented with an eye-tracking system from Senso Motoric Instruments (SMI) that recorded gaze position and movement of both eyes at a rate of 250 Hz. The HTC Vive comes with a ensemble of sensors that capture behavioral changes during user testing (e.g., accelerometers, gyroscopes, proximity sensors).

In the present study, two Vive controllers were used to offer the participant the possibility to interact and move freely with the VR environment. Held in either hand, the user pressed the trigger buttons behind each handheld controller, and was required to maintain the light pressure on these triggers throughout the exploration. Then, he could swing his arms to move forward in the direction where controllers are pointed. The speed in the virtual environment depends on the speed of arm swinging.

Two Vive base stations were placed 4m away from the participant and tracked the Vive controllers to create a 360° virtual space. This virtual space created a "room scale" experiment in which the user could walk fast and slow, stop and interact (e.g., touch a leaf or the building walls). The Vive base stations also detected the 3D position of the helmet. This information was used to assess gaze direction. All tracking was performed with infrared pulses at 60 Hz.

Figure 17: Illustration of the six virtual environments that were created using UNITY. The protocol provided the means to evaluate the impact of color visual environments on user experience. Top row = no color floor marking ; Middle row = RGB color lines (red, blue, green); Bottom row = RGB colors embedded in playful designs.



4.2.2.3 *Objective and declarative evaluation of affective states*

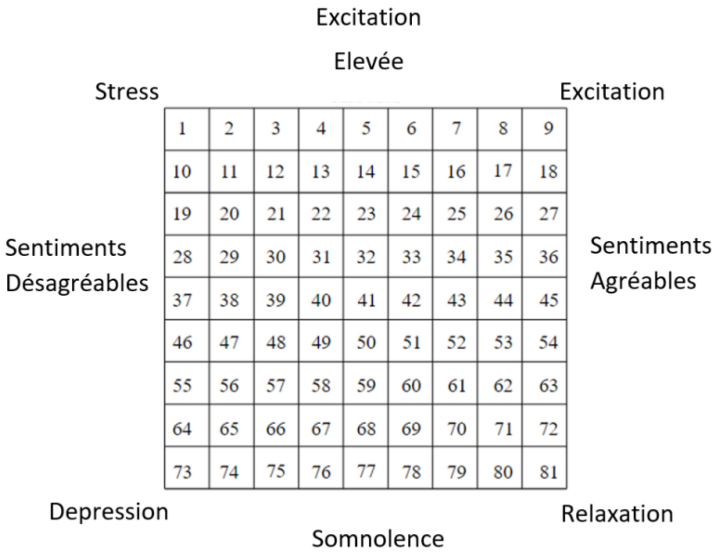
The Empatica E4 wristband is a portable device that provides a real-time physiological data streaming and visualization. In absence of cables, it offers free movement and accurate measurements of cardiac responses (Richardson et al., 2020). The physiological parameters were computed from the blood volume pressure and signal processing was performed with the python's package HeartPy (van Gent et al., 2018; van Gent et al., 2019). In the present study, a third order band-pass Butterworth filter was applied with cutoff frequencies of 0.7 Hz and 3.5 Hz. The matrix of R-R intervals was cleaned from outliers by applying the interquartile range method.

Within the current models of emotion, affect is a neuro-physiological state that is always present and that can arise to consciousness by voluntary re-orientation of attention (Barrett & Bliss-Moreau, 2009). Hence, the use of a self-evaluating grid can help guide individuals to gain an insight on interior states of emotion (Brossard & Delevoye-Turrell, 2021). The self-declared affective experience was here collected with the Feeling and Affect Table to score Arousal and Appraisal (Figure 18). The FAtAAL grid is a 2-dimensional digital scale that is adapted from the Russell grid for Affective States (Russel, 1989). Created on a numerical support, it is a simple-to-use 9-point scale that guides a participant to evaluate her/his overall affective state, considering at once both the intensity (arousal) and the pleasantness (valence) of the experience.

4.2.3 *Design and Measures*

Changes in human behavior can be triggered by explicit (instructions) or implicit factors. In the present case, implicit factors only were manipulated, namely the color of the visual environment. As such, a simple one factor experimental design was used in this experiment. All 6 environments were presented to each participant. Participants were randomly assigned to explore the different VR environments in a total random order.

Figure 18: Illustration of the numerical grid used to self-guide the evaluation of an individual's affective state at a given moment in time.



Participants were encouraged to engage in a spontaneous and natural behavior during free exploration. For this reason, objective measures were collected throughout the experimental session; self-declared questionnaires were to be completed at the end of each block to limit interfering with the user experience.

4.2.3.1 *Spontaneous Motor Behavior*

The time spent exploring each environment was measured in seconds for each type of environment as the time interval between the moment the participant started walking on the path and the moment she/he reached the end of the path. If the participant released the on/of triggers from the controllers, during the walk, a stop was counted. The number of stops were counted for each type of environment and each participant.

Walking speed was calculated from the RawDataBody data, which collected the 3D coordinates of the headset every 200 ms. No calibration process was required as the reference used was in relative coordinates. The total distance was calculated by summing the distance between each frame. Divided by the total time spent in the environment, the average speed in m/s was calculated and converted in km/h.

4.2.3.2 *Gaze Behavior*

The SMI eye-tracking system recorded gaze position and direction. A calibration procedure was required and consisted in a 9-point calibration procedure using a moving white and red point against a grey background, before the start of data collection. The calibration procedure was handled directly with the SMI software that was launched before the Unity application. The calibration for each session was automatically saved in the profile of the participant for the future data analyses.

Gaze direction was classified in 3 categories. It was considered as being straight ahead if it remained within a range of 20° centered around the horizontal gaze line (calculation based on the dot product - see supplementary data). The calculation was performed using the eye-tracking data, which contained information about the unit vector of gaze direction (Y). The proportion of moments for which the parameter Y was between -0.2 and 0.2 was coded as straight ahead gaze; upward gaze direction was considered when Y was greater than 0.2; downward gaze direction was considered when Y was smaller than -0.2.

The entire VR campus was tagged with imaginary areas of interest (AOI) in which the colorful designs were placed in the colorful conditions only. To gain an insight on the role played by color visual environments on gaze behavior, the proportion and the duration of gaze fixations was calculated by summing the total moments in seconds, and divided by the total time spent in the environment for which gaze was directed towards these AOI.

The absence of eye tracking recordings at a given moment in time coded for the presence of an eye blink (True/False in the line BinocularPorValid). In addition, after the detection of a possible eye blink, a time interval of 100 ms was applied before searching for another blink, as the minimum duration of a blink is 100 ms (Schiffman, 1990).

4.2.4 *Changes in Affective States*

Heart rate and heart rate variability have been described as objective indicators of physiological responses related to affective states. Hence, the Empatica E4 gave us the possibility to monitor changes in the affective states of participants without interfering with their free exploration of the VR environments.

Changes in Heart Rate (Delta HR) and in Heart Rate Variability (Delta HRV) were calculated by computing the differences between the average signals collected during exploration and baseline (time interval of 3 minutes before the start of exploration). Delta HR is reported in bpm. Delta HRV was computed with the RMSSD (Root Mean Square of Successive Differences between adjacents NNs). It is unit-less.

Self-declared affective states were collected using the FAtAAL grid. The levels of arousal and valence were calculated by extracting the scores given on each dimension, after the end of environment exploration. A score above 6 for valence indicated a sense of positive affective state.

4.2.5 *Procedure*

4.2.5.1 *Welcome Phase*

Each participant was invited to the laboratory to perform a single session lasting approximately 90 minutes. The study was conducted in a large and quiet room, without windows. Care was taken to clear the area from any obstacles to provide a comforting and reassuring user experience. Air conditioning was used to maintain the temperature of the room at a constant 21° to prevent from overheating and sweating during gait. Finally, pauses were integrated within the protocol to maintain the VR blocks under 15 minutes to limit the emergence of nausea (Birenboim et al., 2019).

Upon arrival at the laboratory, the participant was asked to read and sign a consent form. She/he was then required to put the VR helmet on and to experience a few minutes to familiarize with the task of walking on the spot, moving the arms while moving through a VR environment. The scenes here depicted a good neighborhood outdoor basketball court.

4.2.5.2 *Baseline Phase*

Before the start of the session, each participant was invited to sit for 4 minutes to relax. This was important in order to obtain two types of baseline (resting and stressor baselines) that would then be used to compute relative physiological reactions to the colorful visual environments.

After sitting calmly for 4 minutes, the participant was invited to put the VR helmet on, and the resting baseline was taken for 2 minutes. Then, the participant was invited to engage in a series of mental calculation tasks that consisted in counting backwards from a random four-digit number in steps of a random two-digit number. The researcher informed the participant the following: "You will be monitored carefully during the tasks by the research staff and a buzzer will sound if time you give an incorrect answer." At the end of the mental calculation tasks that lasted 90 seconds, the stressor baseline was taken for 2 minutes (Al-Shargie et al., 2016a; Dedovic et al., 2005a)

4.2.5.3 *Experimental Phase*

Each participant walked in the virtual space under the six types of environments for a total of 60 minutes. The participant was invited to engage in a gait pattern that was spontaneous and easy, to walk at her/his preferred pace, on-the-spot, while moving the arms naturally and freely. At the end of the exploration, the participant took the helmet off and answered the FAtAAL grid on a tablet that was presented to her/him. She/he was then invited to sit and relax for 4 minutes, by for example concentration on her/his breathing behavior. This imposed break out of the VR system provided the means to limit the emergence of discomfort and nausea. Then, she/he put the helmet back on and a 2-min baseline of cardiac responses was taken while the participant staid seated. With the experimenter's help, the participant stood and engaged in the next VR environment. At the end of block 6, the participant received a detailed debriefing by the experiment of the general objectives of the study and was thanked for her/his time.

4.2.6 *Data Processing and Statistical Analyses*

Data processing and analysis were performed with both personal code and algorithms written in Python. They are available as Supplementary Data. Classic null-hypothesis significance tests were applied to reveal the impact of Environment and Order on the user experience. The results obtained in the six virtual Environments (Nature, Nature-Color, Nature-Designs, Urban, Urban-Color and Urban-Designs) were contrasted using non-parametric tests as the normality conditions were not met. The non-parametric Friedman test was applied to reveal the main effects of Environment and Order. The non-parametric Kruskal-Wallis test was applied to reveal the interaction effects, as the groups were unbalanced. The probability level was set to .05 for test interpretation.

4.3 RESULTS

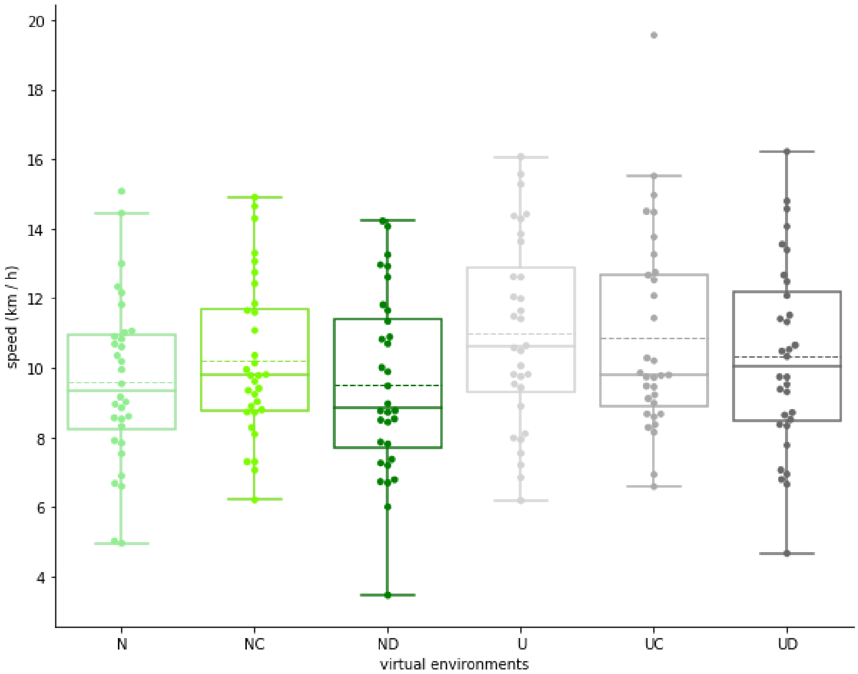
4.3.1 *Walking Behavior*

The speed of spontaneous walking was calculated from the handheld controllers (Figure 16). When the triggers were released, the walking behavior was considered to be a stop in gait. These results test H1 and are presented in Figures 19 and 20.

4.3.1.1 *Number of stops*

The non-parametric Friedman test revealed an absence of effect of Environment on the number of stops, $X^2(5)= 4.81$, $p= .44$. It revealed however a significant effect of Order, $X^2(5)= 15.43$, $p= .009$, with higher scores in the first (M= 2.5, SD= 2.03) than in the second (M= 1.63, SD= 1.04), third (M= 1.69, SD= 1.38), fourth (M= 1.91, SD= 1.71), fifth (M= 1.66, SD= 1.73) and the sixth condition (M= 1.38, SD= 1.01). The Conover's

Figure 19: Bar charts illustrating the impact of Environment on the mean speed of spontaneous walking. N = Nature ; NC = Nature Colors ; ND = Nature Designs ; U = Urban ; UC = Urban Colors ; UD = Urban Designs.

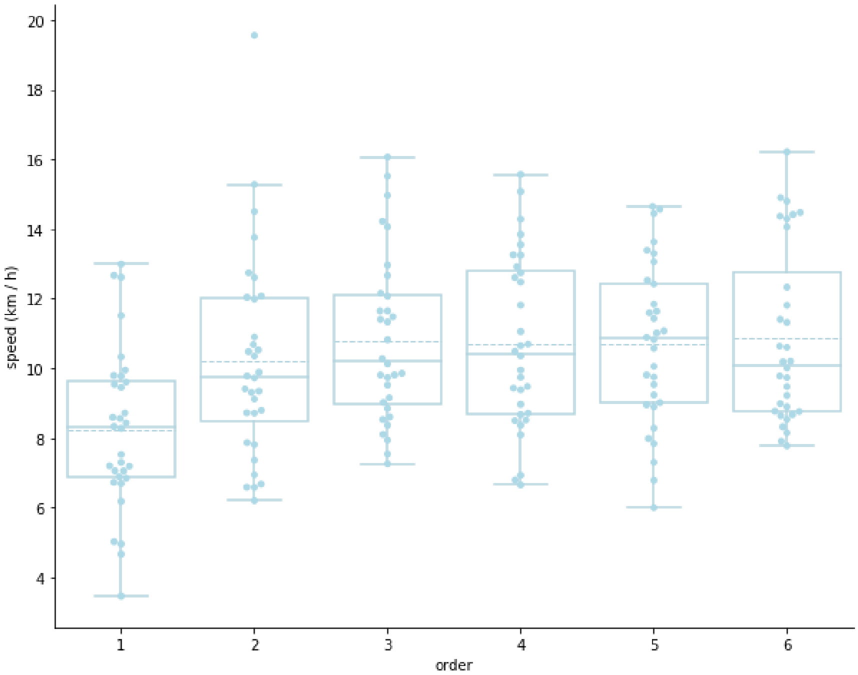


post hoc test confirmed significant differences between first and second (p= .02), first and third (p= .005), first and fifth (p= .007) as well as first and sixth ($p < .001$). The interaction Environment * Order was non significant, $X^2(5)= 3.03$, p= .70.

4.3.1.2 *Walking speed*

The non-parametric Friedman test revealed a significant main effect of Environment on the speed of spontaneous walking, $X^2(5)= 20.25$, p= .001, with higher scores in Urban (M= 11, SD= 2.72) and Urban Colors (M= 10.86, SD= 2.86) than in Nature (M= 9.61, SD= 2.4), Nature Colors (M= 10.23, SD= 2.26), Nature Designs (M= 9.52, SD= 2.58) and Urban Designs (M= 10.32, SD= 2.72). The Conover's post hoc test confirmed significant differences between Urban and Nature ($p < .001$), Urban and Nature Colors (p= .04), Urban and Nature Designs ($p < .001$) as well as Urban and Urban Designs (p= .03). The differences were also significant between Urban Colors and Nature (p= .01) as well as Urban Colors and Nature Designs (p= .009).

Figure 20: Bar charts illustrating the impact of Order on the mean speed of spontaneous walking. 1-6 = block 1 to block 6.

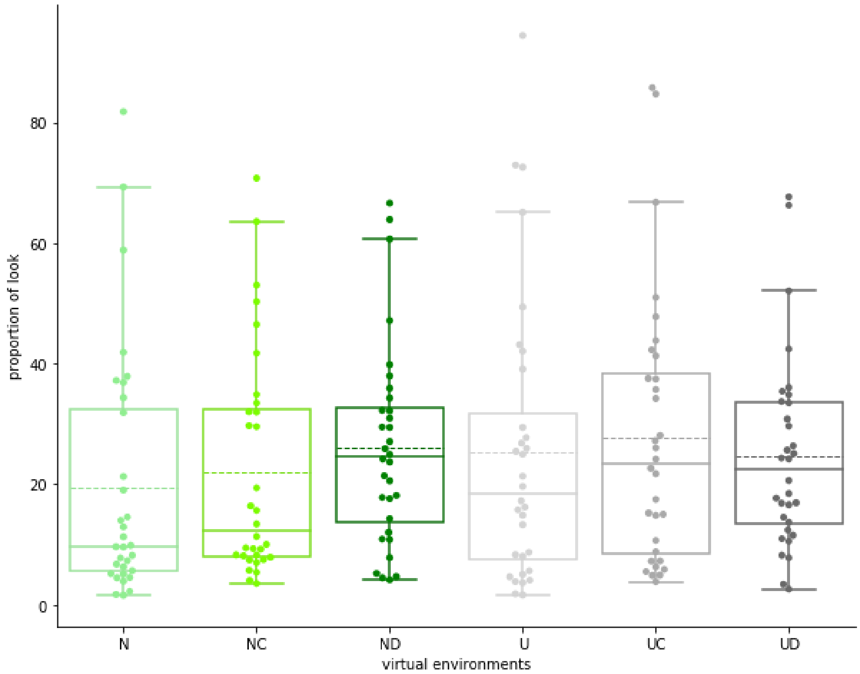


The non-parametric Friedman test also showed a significant main effect of Order, $X^2(5)= 49.57$, $p < .001$, with lower scores in the first (M= 8.25, SD= 2.31) than in the second (M= 10.2, SD= 2.91), third (M= 10.8, SD= 2.37), fourth (M= 10.71, SD= 2.47), fifth (M= 10.7, SD= 2.33) and the sixth block (M= 10.87, SD= 2.51). The Conover's post hoc test confirmed significant differences between the first condition and all other conditions ($p < .001$). The differences were also significant between the second and the fifth (p= .048) as well as the second and the sixth condition (p= .02). The interaction Environment * Order was non significant, $X^2(5)= 5.18$, p= .39.

4.3.2 *Gaze Behavior*

The eye-tracking system that was integrated within the HTC Vive helmet provided the means to assess gaze orientation with the calculation of the proportion of time looking directed towards the ground and straight ahead, the duration of gaze fixations and eye blink rates for each participant. These results test H2 and H3 and are presented in Figures 21 and 22.

Figure 21: Bar charts illustrating the impact of Environment on the mean proportion of time looking towards the floor. N = Nature ; NC = Nature Colors ; ND = Nature Designs ; U = Urban ; UC = Urban Colors ; UD = Urban Designs.

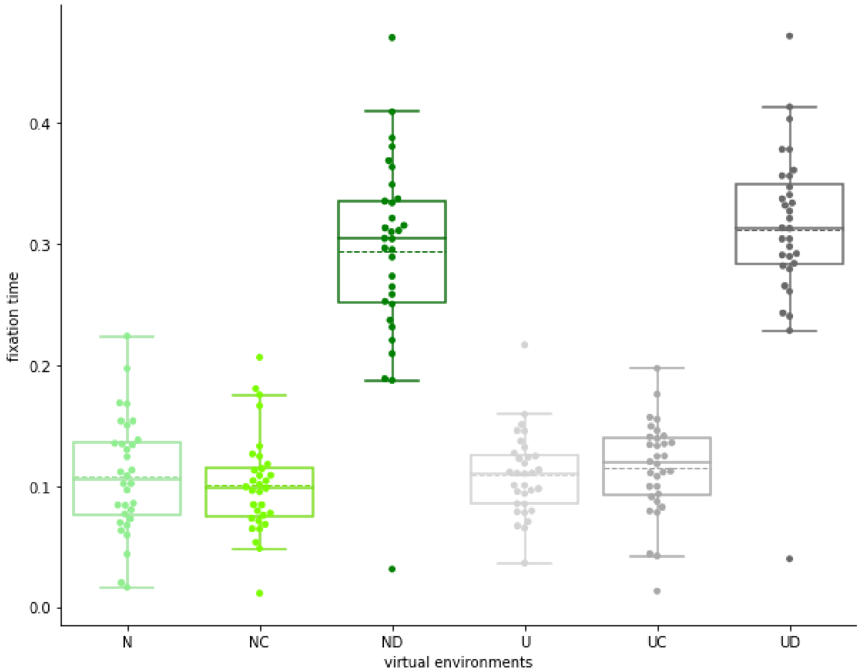


4.3.2.1 *Proportion of time looking*

The non-parametric Friedman test showed a significant main effect of Environment on the proportion of time looking towards the floor, $X^2(5)= 16.77$, p= .005, with lower scores in Nature (M= 19.46, SD= 20.61) than in Nature Colors (M= 22.02, SD= 18.82), Nature Designs (M= 26.13, SD= 16.62), Urban (M= 25.4, SD= 23.67), Urban Colors (M= 27.69, SD= 22.16) and Urban Designs (M= 24.71, SD= 16). The Conover's post hoc test confirmed significant differences between Nature and Nature Designs (p= .004), Nature and Urban (p= .02), Nature and Urban Colors ($p < .001$) as well as Nature and Urban Designs (p= .002). The differences were also significant between Nature Colors and Urban Colors (p= .049). The non-parametric Friedman test revealed an absence of Order effect, $X^2(5)= 7.73$, p= .17.

The non-parametric Friedman test showed a significant main effect of Environment on the proportion of time looking straight ahead, $X^2(5)= 14.5$, p= .01, with higher scores in Nature (M= 78.91, SD= 20.25) than in Nature Colors (M= 76.58, SD= 18.5), Nature Designs (M= 72.14, SD= 16.73), Urban (M= 73.15, SD= 23.1), Urban Col-

Figure 22: Bar charts illustrating the impact of Environment on the mean duration of gaze fixations in seconds towards the areas of interest. N = Nature ; NC = Nature Colors ; ND = Nature Designs ; U = Urban ; UC = Urban Colors ; UD = Urban Designs.



ors (M= 71.55, SD= 21.96) and Urban Designs (M= 73.85, SD= 15.95). The Conover's post hoc test confirmed significant differences between Nature and Nature Designs (p= .005), Nature and Urban (p= .03), Nature and Urban Colors (p= .003) as well as Nature and Urban Designs (p= .004). The non-parametric Friedman test revealed an absence of Order effect, $X^2(5)= 8.45$, p= .13.

4.3.2.2 *Duration of gaze fixations*

The non-parametric Friedman test showed a significant main effect of Environment on the proportion of gaze fixations towards the AOI ($X^2(5)= 111.125$, $p < .001$) with higher scores in Nature Designs (M= 0.29, SD= 0.08) and Urban Designs (M= 0.31, SD= 0.07) than in Nature (M= 0.11, SD= 0.05), Nature Colors (M= 0.10, SD= 0.04), Urban (M= 0.11, SD= 0.04) and Urban Colors (M= 0.12, SD= 0.04). The Conover's post hoc test confirmed significant differences between Nature Designs and Nature ($p < .001$), Nature Designs and Nature Colors ($p < .001$), Nature Designs and Urban ($p < .001$) as well as Nature Designs and Urban Colors ($p < .001$). The differences were also significant between Urban Designs and Nature ($p < .001$), Urban Designs and Nature Colors ($p < .001$), Urban Designs and Urban ($p < .001$) as well as Urban Designs and Urban Colors ($p < .001$).

The non-parametric Friedman test also showed a significant main effect of Order, $X^2(5) = 16.7$, $p = .005$, with lower scores in the fifth (M= 0.13, SD= 0.08) than in the first (M= 0.19, SD= 0.1), second (M= 0.18, SD= 0.1), third (M= 0.15, SD= 0.1), fourth (M= 0.2, SD= 0.13) and the sixth block (M= 0.19, SD= 0.12). The Conover's post hoc test confirmed significant differences between the fifth and the first ($p = .02$), the fifth and the second ($p = .02$) as well as the fifth and the fourth condition ($p = .02$). The interaction Environment * Order was non significant for the duration of gaze fixation.

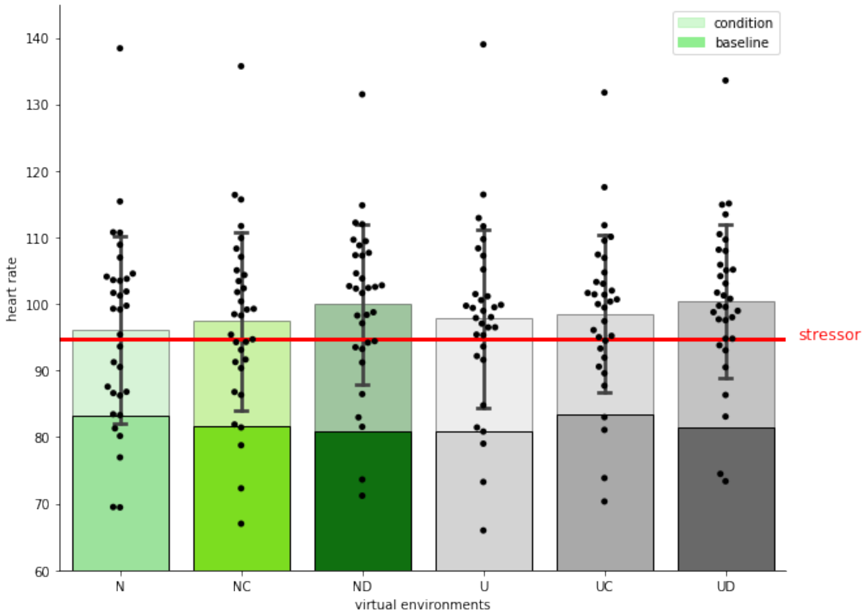
4.3.2.3 *Blinking Rates*

The non-parametric Friedman test revealed an absence of Environment effect on the number of eye blinks per minute, $X^2(5) = 5.95$, $p = .31$. The effect of Order was also non significant, $X^2(5) = 8.38$, $p = .14$. Overall, these findings suggest a similar level of cognitive load across experimental conditions.

4.3.3 *Emotional responses*

The Empatica E4 wristband offered an accurate measurement of changes in heart rate (HR) and in heart rate variability (HRV) throughout the VR task. Results are presented in Figures 23, 24 and 25. Human behavior is often associated to changes in perceived user experiences. Hence, in addition to objective measures, it is important to collect the declarative experience of participants. In the present study, user experiences were obtained at the end of each block with the FAtAAL numerical grid. Results are presented in Figures 26 and 27.

Figure 23: Bar charts illustrating the impact of Environment on the mean changes in heart rate. N = Nature ; NC = Nature Colors ; ND = Nature Designs ; U = Urban ; UC = Urban Colors ; UD = Urban Designs.



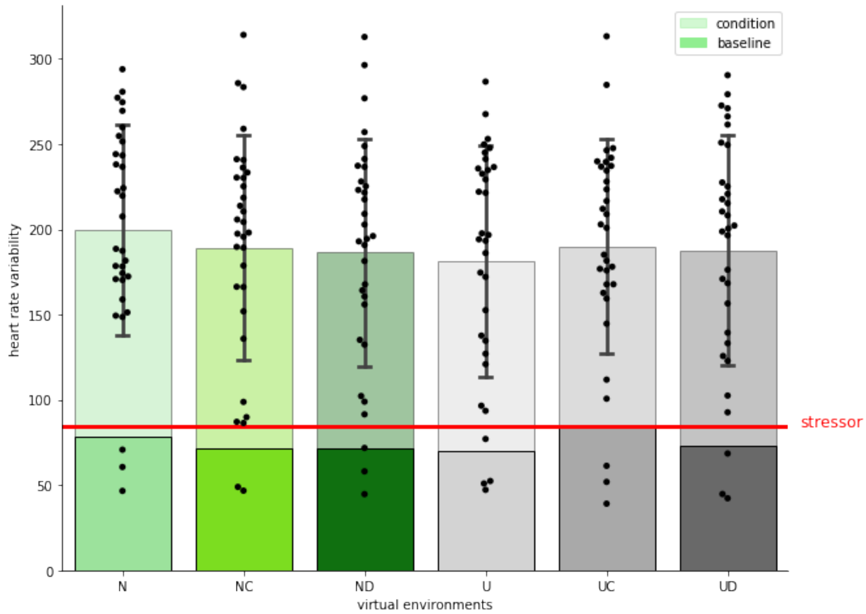
4.3.3.1 *Changes in Heart Rate*

The non-parametric Friedman test revealed a main effect of Environment on the changes in HR, $X^2(6)= 16.63$, p= .01, with lower scores in the baseline stressor (M= 11.33, SD= 12.31) than in Nature (M= 12.93, SD= 19.85), Nature Colors (M= 15.74, SD= 16.93), Nature Designs (M= 19.16, SD= 15.45), Urban (M= 17.05, SD= 17.31), Urban Colors (M= 15.13, SD= 18.07) and Urban Designs (M= 19.03, SD= 14.65). The Conover's post hoc test confirmed significant differences between Stressor and Nature (p= .04), Stressor and Nature Colors (p= .02), Stressor and Nature Designs ($p < .001$) as well as Stressor and Urban Designs (p= .002). The differences were not significant between the Stressor and both the Urban and Urban Colors conditions. The non-parametric Friedman test revealed an absence of Order effect, $X^2(5)= 5.7$, p= .34.

4.3.3.2 *Changes in Heart Rate Variability*

The non-parametric Friedman test revealed a main effect of Environment on the changes in HRV, $X^2(6)= 16.63$, p= .01, with lower scores in Stressor (M= 8.30, SD=

Figure 24: Bar charts illustrating the impact of Environment on the mean changes in heart rate variability. N = Nature ; NC = Nature Colors ; ND = Nature Designs ; U = Urban ; UC = Urban Colors ; UD = Urban Designs.



63.06) than in Nature (M= 121.55, SD= 88.48), Nature Colors (M= 118.08, SD= 74.15), Nature Designs (M= 115.15, SD= 82.74), Urban (M= 111.2, SD= 76.98), Urban Colors (M= 106.22, SD= 83.55) and Urban Designs (M= 114.41, SD= 83.27). The Conover's post hoc test confirmed significant differences between stressor phase and all other environments ($p < .001$) but an absence of differences between conditions.

The non-parametric Friedman test revealed a main effect of Order on the changes in HRV, $X^2(5)= 11.71$, $p= .04$, with lower scores in the first (M= 88.14, SD= 75.59) than in the second (M= 120.3, SD= 81.93), third (M= 109.99, SD= 81.02), fourth (M= 121.89, SD= 89.84), fifth (M= 122.96, SD= 78.51) and the sixth condition (M= 123.35, SD= 77.13). The Conover's post hoc test confirmed significant differences between the first and the second ($p= .01$), the first and the fourth ($p= .009$), the first and the fifth ($p= .009$) as well as the first and the sixth ($p= .007$). The interaction Environment * Order was non significant, $X^2(5)= 1.84$, $p= .87$.

4.3.3.3 *Perceived valence and arousal*

The non-parametric Friedman test revealed a main effect of Environment for Valence, $X^2(5)= 23.41$, $p < .001$, with lower scores in Urban (Mdn= 5) and Urban Colors (Mdn=

Figure 25: Bar charts illustrating the impact of Order on the mean changes in heart rate variability. 1-6 = block 1 to block 6.

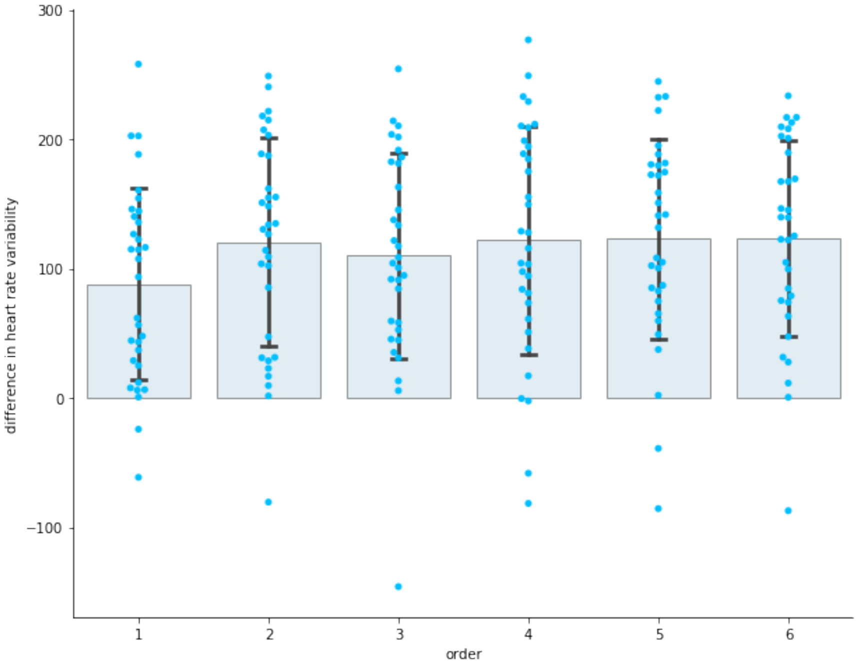


Figure 26: Bar charts illustrating the impact of Environment on the Valence dimension of the FATaaL grid to report the perceived pleasure experienced during spontaneous walking in the six virtual environments. N = Nature ; NC = Nature Colors ; ND = Nature Designs ; U = Urban ; UC = Urban Colors ; UD = Urban Designs.

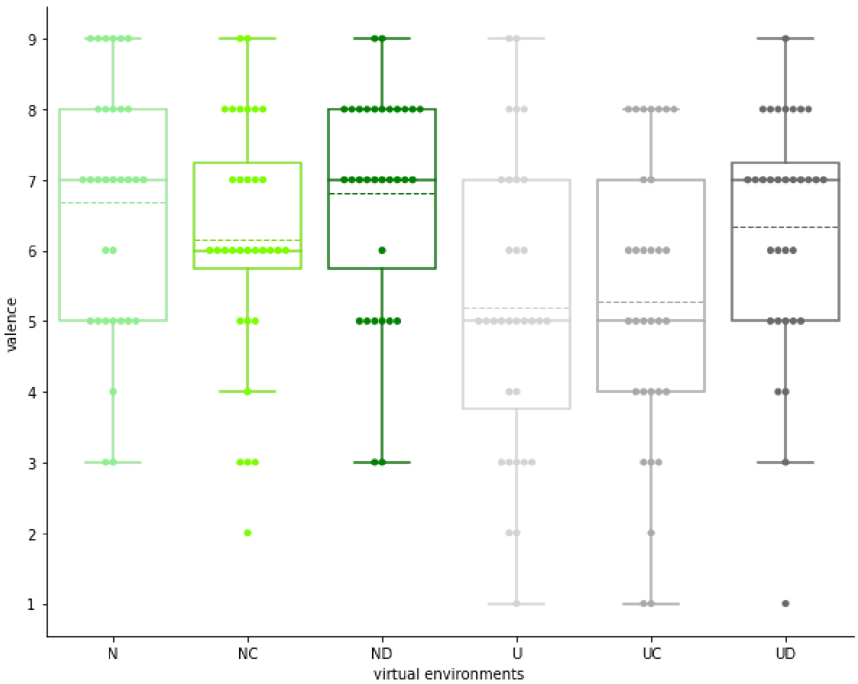
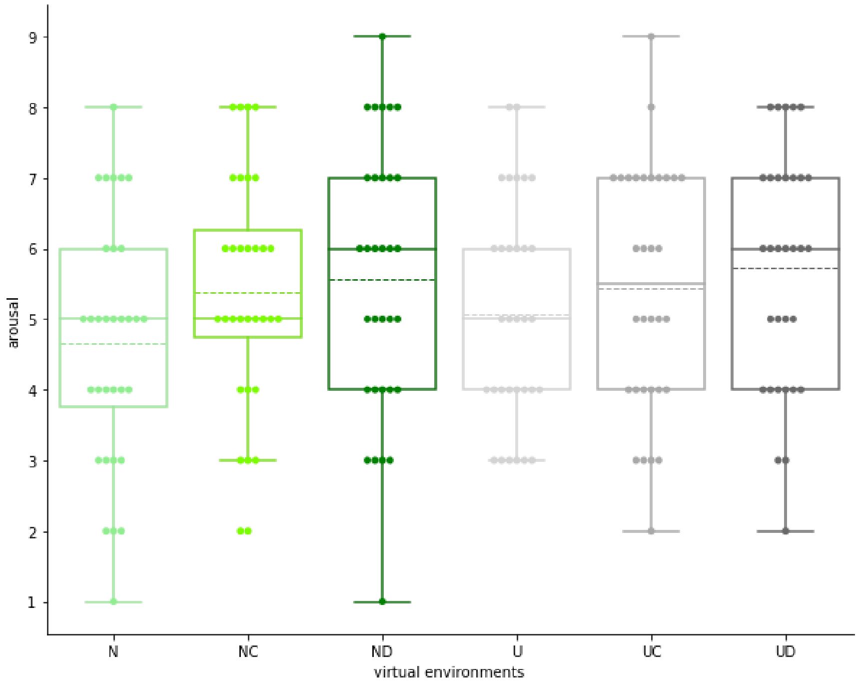


Figure 27: Bar charts illustrating the impact of Environment on perceived Arousal dimension of the FATaaL grid to report the perceived arousal experienced during spontaneous walking in the six virtual environments. N = Nature ; NC = Nature Colors ; ND = Nature Designs ; U = Urban ; UC = Urban Colors ; UD = Urban Designs.



5) than in Nature (Mdn= 7), Nature Colors (Mdn= 6), Nature Designs (Mdn= 7) and Urban Designs (Mdn= 7). The Conover's post hoc test confirmed significant differences between Urban and Nature (p= .001), Urban and Nature Colors (p= .03), Urban and Nature Designs (p < .001) as well as Urban and Urban Designs (p= .005). The differences were also significant between Urban Colors and Nature (p= .01), Urban Colors and Nature Designs (p= .002) as well as Urban Colors and Urban Designs (p= .04). The effect of Order was non significant for Valence, $X^2(5)= 7.63$, p= .18.

The non-parametric Friedman test revealed a main effect of Environment for Arousal, $X^2(5)= 15.5$, p= .008, with higher scores in Nature Designs (Mdn= 6) and Urban Designs (Mdn= 6) than in Nature (Mdn= 5), Nature Colors (Mdn= 5), Urban (Mdn= 5) and Urban Colors (Mdn= 5.5). The Conover's post hoc test confirmed significant differences between Nature and Nature Designs (p= .007) as well as Nature Designs and Urban (p= .02). The differences were also significant between Nature and Urban

Designs (p= .002) as well as between Urban and Urban Designs (p= .007). The effect of Order was non significant, $X^2(5)= 3.01$, p= .70.

4.4 Discussion

Virtual reality (VR) is the use of computer technology to create a simulated environment. Our aim was to show how VR may open new avenues to psychological testing. We report data and scripts that describe the psychological experiences of human users in an ecologically-valid behavioral task. More specifically, we report that color-design principles can promote similar changes in a virtual environment than that observed in natural settings.

Our findings confirmed that vegetation led walkers to slow down their walking pace. An interaction was reported indicating that colorful designs had a stronger impact on walking pace when placed in urban than in green environments. Hence, H1 was confirmed. Gaze strategy was significantly impacted by the presence of colorful designs; however, lower and longer gaze fixations were observed with than without colorful designs, in both urban and green environments. Hence, H2 was only partially confirmed. Eye blink rates were not impacted by the visual elements; hence, H3 was not verified. Finally, both self-declared and objective physiological measures confirmed the impact of colorful designs in rendering the experience more pleasurable, confirming H4. Overall, our results argue in favor of virtual reality as a proxy tool to collect psychological measures, characterizing the impact of real environments on user experience.

4.4.1 *Color walks in urban and green environments*

The first objective of this study was to assess the impact of colorful designs on spontaneous motor tempo when walking in the urban space. We measured walking speed, which in previous research was reported to be associated to stress levels (Franěk et al., 2018). After creating a VR environment of the university campus, a total of six conditions were created. Results indicated a significant effect of VR conditions on the spontaneous pace of walking: participants spent significantly more time when walking in the green conditions (Nature, Nature Color Lines and Nature Color Designs) than in the Urban conditions. These findings successfully replicated previous results suggesting that vegetation lead walkers subconsciously to slow down their walking pace (Franěk, 2013). Additionally, we observed that walking pace was similar in the green environments and in the Urban Color Design conditions, suggesting that colors can play a similar role than nature when integrated in a design pattern. This finding reinforces the idea that colored patterns may impact spontaneous walking (Nikolopoulou et al., 2016b) and decrease perceived stress. However, color alone was not sufficient: no effects were observed on walking speed when colored lines only (e.g., red, blue, and green) were presented within the gray urban scenes. Two studies have reported contrasting conclusions (Meier et al., 2012; Mentzel et al., 2019). However, their results could have come from other non-controlled sources (changes in weather, urban density and noises).

4.4.2 *Gaze travel in urban and green environments*

Our second objective was to quantify changes in gaze behavior within a VR environment. The technological challenge here was the fact that very few systems provide the means to track eye movements with sufficient accuracy for scientific exploitation.The SMI system offers high quality evaluation of gaze position in VR environments. After a short calibration, gaze position was recorded as a function of time and offered a reconstruction of gaze travel with high accuracy ($< 0.8°$). The personal scripts written in python for gaze analyzes are available for future users, following the open science principles. Our results indicated that participants fixated significantly more times the trail (ground) when walking in the urban than in the green environments. This finding confirms the suggestion that nature walks free gaze (J.Martínez-Soto et al., 2019) and helps individuals lose track of time (M. Davydenko & J. Peetz, 2017). In the city, gaze is captured by the cluttered visual environment and engages attention; such noisy visual surroundings is a plausible explanation of why cities are perceived as mentally tiring. A freeing gaze is a source of mental relaxation. The data reported here confirm the restorative effect of virtual green environments with lower proportions of gaze fixation in the green environments (Nature and Nature Color Lines). On the other hand, the colorful design, limited the freezing of gaze.

Designs impacted gaze travel when presented in urban but also in the green environments. They nudged the walkers to look at the ground more often and to adopt longer fixations times. These eye fixations were even more frequent and longer in the nature Design environments than that observed in the extreme absence of colors, i.e., in the gray urban environment. Overall, our results are consistent with the claim that the complexity of the ground surface has an impact on the direction of gaze and leads citizens to monitor more often the walking surfaces.

Colors are identified faster than other features like shape and size (MacKay & Ahmetzanov, 2005). Therefore, urban planners could use our VR method and use scientifically based visual interventions to encourage citizens to pay attention to ground surfaces, e.g., when a road is under construction or in threat of flooding. The use of color-design principles could be also used to guide popup interventions that would control gaze travel through the city and the woods. Used to catch the attention, designs could also be created stick out and capture the curiosity of pedestrians, nudging more active life styles.In all these case studies, VR would be a well suited and innovating tool to guide design choices of such interventions.

4.4.3 *Feel good experiences in green environments*

The third objective of our work was to test whether the implementation of green and color elements in an urban environment would impact the affective states of the users. We used similar questionnaires than those used in real-world experiments and traced changes in perceived arousal (intensity) and perceived pleasantness (valence) of the experience (Russel, 1989). Participants reported significantly less pleasure when walking in the urban conditions than when strolling through the green environments. These findings are in line with previous research showing that nature makes walking more enjoyable (Pasanen et al., 2018). Furthermore, we observed that levels of pleasure were similar in the green and in the urban color design condition, confirming that colorful playful interventions could be a motivator for pedestrian activity (Donoff, 2017).

With the possibility to control for order effect, our VR methodology further demonstrated the impact of colorful designs in creating interest and arousal. Indeed, our participants felt significantly more aroused when walking in the Nature Designs and Urban Designs conditions than in all other conditions. These results were furthermore confirmed by the objective measures of arousal. Participants experienced a significant increase in heart rate in both designs conditions compared to all other conditions, including the baseline stressor. Hence, colorful designs can be a tool to project low arousal but also high-arousal positive affects in living environments (McManus et al., 2019).

4.5 LIMITATIONS

Although this current research has significant effects, several factors should be taken into consideration when interpreting our results. Firstly, the participants in the current study were all young French adults in good health without vision problems, so they constituted an homogeneous sample of users. Previous research has shown that pedestrian behavior also depends on vision disabilities (Turano et al., 2001). Walkers with normal vision directed their gaze primarily ahead or at the goal, whereas walker with vision impairments directed their gaze primarily towards the ground and walls. Gender as well plays an important role on pedestrian behavior, with male pedestrians taking more risks than women e.g., for crossing roads (Fotios et al., 2014). Finally, color preferences can be impacted by nationality (Chebat & Morrin, 2007): French Canadians considered produces to be of better quality when the shopping mall was decorated with warm colors. Instead, Anglo-Canadians related quality to cool colors. Given the above, our results may not be generalizable to more heterogeneous populations samples.

Secondly, we adopted an experimental design that recorded short trials to avoid fatigue and nausea. Hence, the familiarisation phase was short, which may be the cause of certain order effects reported in the results section. More importantly, parameters such as cognitive performance and electrodermal activity could not be measured. Indirect measures were proposed with, for example, the measure of blink rates and heart rate variability (HRV) to estimate cognitive load and physiological stress, respectively. However, even if a tendency was observed for the later, we report an absence of significant effects; hence, we can not here report data to confirm the beneficial effects of green and colorful elements on well being. Further developments in VR technology will quickly offer the means to implement longer trials, which will be key to further study the influence of color interventions in the urban environment on cognitive stress.

Finally, this study used a limited number of designs and a unique urban setting. Hence, we can not report on the impact of, e.g., shape, size, brightness and achromatic patterns of design elements in the environment. Our aim here was to demonstrate the usefulness of VR technology in design choices. Future studies will be able now to further develop our code to consider more specifically what design principles can impact a pedestrian's walking experience to nudge the desire to be active.

4.6 CONCLUSION

Cities are designed to protect and meet the needs of humans. However, studies suggest that living in a congested urban environment is unhealthy, and it is one of the first factors that has a detrimental impact on people's physical and mental health (Sarkar & Webster, 2017). The research question was here to demonstrate that virtual reality could be a tool used to reveal the power of color designs in restoring well-being and pleasure in stressful urban environments.

Our work successfully replicated the positive restorative effects of green environments on pleasure and well-being in adult pedestrians. Furthermore, it confirmed that colorful floor marking could be a promising tool to transform dull environments in temporary and low-cost interventions because designs catch the attention of the eye and arises the curiosity of pedestrians. As our results are consistent with previous research, the research direction reported here can assert that virtual reality is a useful and effective tool for evaluating different urban design scenarios. Nevertheless, virtual reality studies need to be complemented by field experiments, as real-life variants can impact laboratory-based research findings and conclusions.

4.6.1 *Acknowledgments*

The authors thank Nicolas Bremard and Samuel Degrande for their help in eye tracking implementation within the VR system. Special thanks to Yoann Sarels and his team (VERTICAL SARL) for the creation of the virtual reality environment of the university campus.

Part III

FIELD EXPERIMENTS

5

PLAYFUL' CITY A LIVING LAB APPROACH

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Authors: Adamantia BATISTATOU

Local actions for urban sustainability and do it your self-solutions are blooming. Simultaneously, in response to the financial crisis, small-scale bottom-up interventions became the mainstream strategy for city planners seeking to improve urban living. (Bravo, 2020). Low-cost temporary interventions like, floor marking and pop-up solutions, are used to lead the pedestrians towards city sites of interest for example, towards parks, sports facilities or museums and cultural events. How could we use these types of creative procedures and interventions to promote soft mobility? How could create a collaboration between stakeholders, artists, researchers and inhabitants working together for rethinking, street design and evaluate urban walkability? Living labs have become a very popular tool to create collaborations between the different actors of a city and to bridge this gap between innovation and efficiency.

5.1 INTRODUCTION

Living laboratories originally appeared in the early 1990s as part of a Drexel University College of Business and Administration course, that required students to work on real-world projects in an inner-city setting.Students quickly understood that large scale region or cultural problem have a huge number of stakeholders to consider, and that requires a multidisciplinary approach(Bajgier et al., 1991).Living labs, according to the European Network, are open innovation ecosystems that combine research and innovation processes in real-world communities and environments, based on collaboration and co-creation with users(of Living Labs, 2015).

Now the Living Lab' approach has been adopted in various contexts such as, in social innovation (Schaffers et al., 2009), in new technologies (Cardone et al., 2014), in health (Swinkels et al., 2018) and in sustainability (Voytenko et al., 2016).The living labs that address territorial innovation in urban and regional settings, are defined as Urban living labs (Steen & Van Bueren, 2017a).This research approach has become a popular tool for forming collaborative relationships among diverse stakeholders in order to produce more effective innovative solutions.

The Living Lab process is increasingly used for enhancing soft mobility in the urban setting such as for promoting cycling(Huang et al., 2018), with the aim to reduce the gap between urban planning and the current development of the mobility sector.However, living labs to promote walking in urban areas should be developed to address the fundamental difficulties of urban walkability such as safety, accessibility and comfort.Different nudging designs must be conceived and tested in conjunction, with effective public consultation and communication to improve pedestrian environments.

5.2 Living labs characteristics

Despite the fact that living labs examine a diversity of different challenges, they all have common fundamental components (Steen & Van Bueren, 2017a).Firstly, living Labs aim to generate innovation. They aim to learn and find new solutions to existing problems, by developing products or services. Secondly, they necessitate the active involvement of stakeholders and users such as policymakers, private actors, local associations and end-users.Thirdly, this process requires a multi-method approach for developing and evaluating different design solutions.Finally, urban living labs are distinguished by the fact that they take place in real life settings.See Figure28

Figure 28: Main elements of a Living Lab.

5.3 CASE STUDY: PLAYFUL CITY

In 2017, the Mobility department of the region Hauts-de-France was seeking solutions to get the population of Lille to engage more in spontaneous physical activity. At that time, I was a game designer and I was interested in user testing and in playable cities. I contacted Professor Yvonne N. Delevoye-Turrell to see how cognitive tools could be included in my thinking; We quickly decided to engage in a research project together. We answered a call launched by the MEL in 2018 and in collaboration with the Mobility department of the MEL, the Playful City case study started in February 2019.

Playful City followed the living lab process (Steen & Van Bueren, 2017b) and featured local design interventions with the aim to foster walking in the urban spaces of the Metropolitan area of Lille (MEL). A living lab was installed on the campuses of the University of Lille for a period of two years (2019-2020). The scientific campus of the University of Lille was selected upon the request of the university for a design intervention that would promote the physical activity and the well-being of the users of the campus. The open space of the library of the university was used to contact workshops with the users.

Because the project was under the authority of the university, the stakeholders were people from the sports department of the university, from the mobility department, the geography department and the personnel working on the campus grounds. The action of these stakeholders was coordinated by the vice president for physical activity of the University, professor Muriel Garcin and her team.

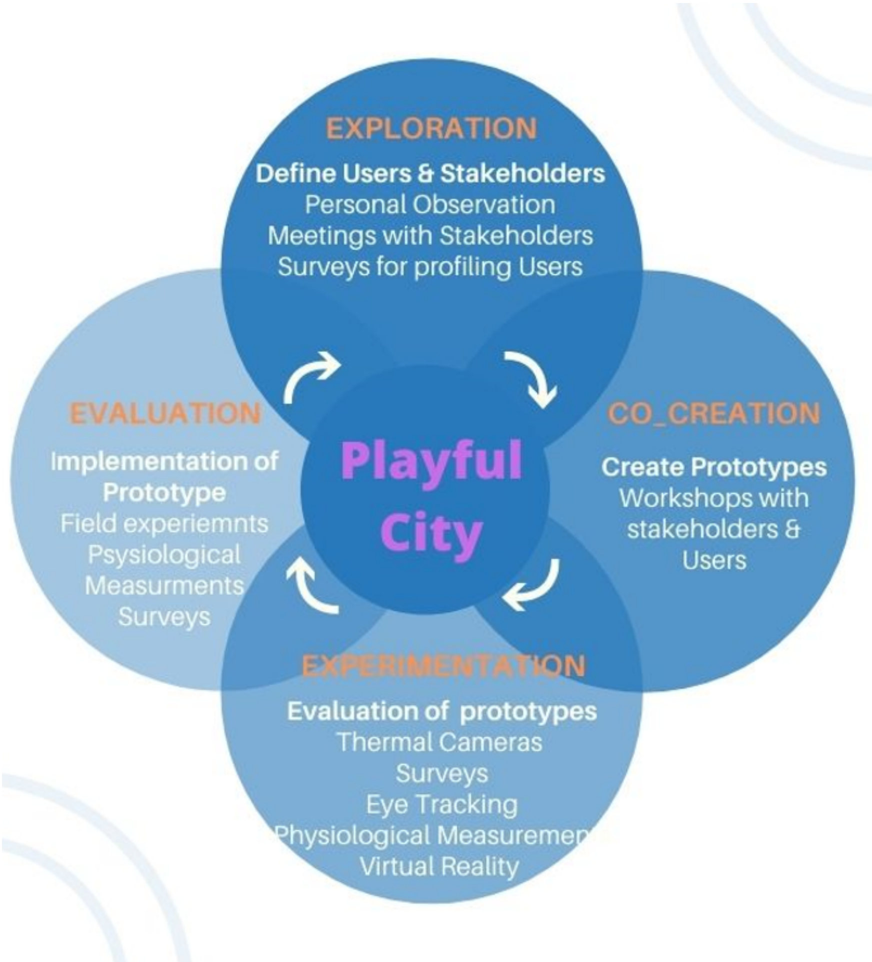
The objective of Playful City was to create surprising sensory environments to invite citizens to discover the pleasure to walk. The strategy used was to promote active citizenship in everyday life through playful colorful designs. Using the methods of experimental psychology, we aim to scientifically evaluate the role played by design interventions to determine what would be the elements that promote a more active lifestyle.

The results of the case study were presented and included within the framework of the World Design 2020 program.

5.4 OVERVIEW OF MY METHOD

The research methodology developed and implemented at the Playful City case study, is based on the living lab process. It followed the four-phase principle. The first phase was the exploration phase. This step aimed to understand the user's walking habits inside the campus of Lille and to develop possible partnerships with stakeholders. At this stage, the objectives of the research project were defined. The second phase was the co-creation phase. Concepts for design prototypes emerged from several sessions of workshops that were organized with stakeholders and users. The third phase was the test phase. This phase aimed to test and evaluate different scenarios of prototypes. The fourth and final phase was the implementation-evaluation phase. This phase aimed to implement and evaluate the design solution selected in the real-life setting, see Figure29.

Figure 29: Playful City Process.



5.5 PHASE 1. EXPLORATION

The aim of this phase was to explore walking experiences in the campus, understand the walking habits of the users and develop collaborations with the stakeholders. This phase was completed following three actions:

ACTION 1: Observation. I conducted a personal observation by walking around the campuses at various times of the day and week to observe and note design obstacles and opportunities for promoting walking.

ACTION 2: Engage Stakeholders. Several meetings with the stakeholders of the university took place during this case study. My objective was first to engage stakeholders and then, to bring them to understand the importance of design thinking with the users.

ACTION 3: Identify User's profile. A questionnaire was created in collaboration with the stakeholders of the university, in order to gather demographic data of the users. A total of 71 students of the university replied to the survey.The demographic profile of the respondents is set out in Figure30 below.

Figure 30: Demographic profile of users

N=71	
Gender	
Male	58
Female	13
Average age	20.408
SD	5.228
In which mode of transport are you coming to the university?	
Car	20%
Bus	20.95%
Metro	36.19%
Bicycle	1.90%
Walking	20.95%
Perceived estimation walking time inside the campus	
Mini	5 minutes
Max	30 minutes
Do you spend free time on campus?	
Yes	47%
No	53%
Other	
Are you doing sports in your free time?	
Yes	23%
No	77%
Are you physically active inside on campus?	
Yes	20%
No	69%
Other	11%

5.6 PHASE 2. CO-CREATION

The aim of this phase was to co-create walking pathways with the users and stakeholders. At this moment, two actions were conducted.

ACTION 1: Participatory Map with stakeholders. The goal of this stage, was to set the objectives of the stakeholders and to ensure feasibility of the project. Several meetings and walking sessions took place in order to discus and validate design propositions for the realization of the prototype. The participatory photo method

(PPM) was used during the walking sessions to identify the points of interest of the campus according to stakeholders (Dennis Jr et al., 2009). A total of five stakeholders participated (the vice presented of the sports facility of the university, sport teachers and garden planners). The task was to walk with the researchers around the campus and take pictures of the areas that were to guide pedestrians, see Figure32. The main points of interest that emerged from the walking sessions were: (1) the sports facilities of the campus that they were under used; (2) the different building facilities of the university because it is large, cold and difficult to navigate within. See Figure 31 and Figure 32.

Figure 31: Map of points of interest.

ACTION 2:Participatory Map with students. In this phase, the walking routines of the students needed to be defined.The goal was to define the paths followed by the users inside the campus boundaries, and the density of the existing walking paths.The outcome of this phase was the co-creation of the student's walking map of the campus, see Figure34.

The participatory map is a tool that is often used in urban planning for understanding the habits of the user and engage the user in the research process (Huybrechts et al., 2012).It is focused on the user's perception of the environment. Participants sample number was 60 students.The users were asked to color the different walking

Figure 32: Walking session with stakeholders.

paths that they take during their stay in the campus.The researcher noted how many users take the same path; this provided the possibility to calculate the intensity of use of the existing paths. See Figure 33.

5.7 PHASE 3. TEST

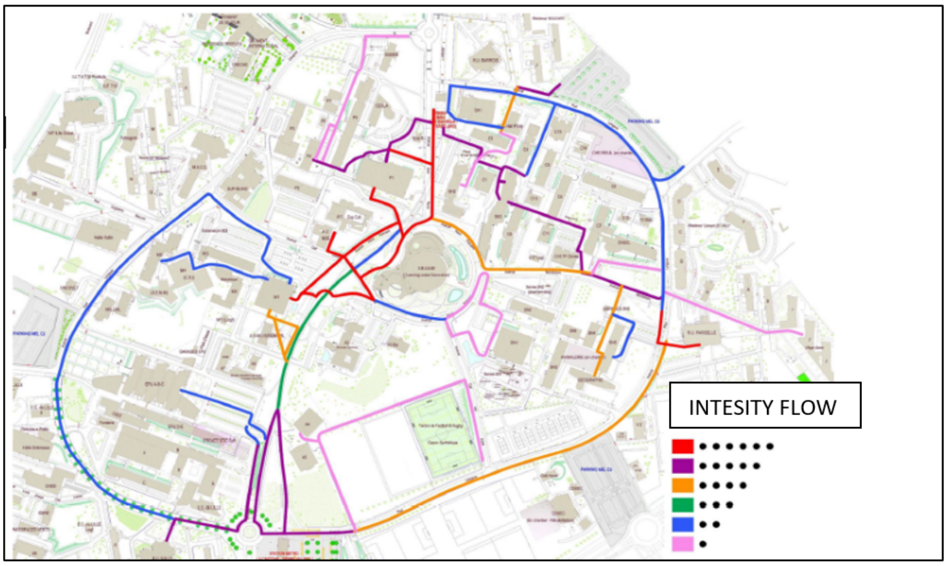
In the third phase, the design solution of colorful floor markings was tested through a series of laboratory-based studies to determine scientifically-based design principles (presented in the Part II of my thesis).

From the third phase, a series of scientifically-based design principles were extracted. In collaboration with designers from the project Lille World-design 2020 (C.Diancourt), a series of prototype color-designs were then made (Studio Lebleu ; La Condition Publique - Roubaix). The implementation on the Scientific Campus of the University of Lille was performed by the technicians from La Condition Publique and the University landscape department. We give special thanks here to Mme M.

Figure 33: Procedure of Participatory Map

Garcin and her team from the University Department of Sport Facilities for the coordination of this implementation phase.

Figure 34: Student's Participatory Map



5.8 PHASE 4. IMPLEMENTATION AND EVALUATION

From phases 1 and 2, it was decided to create two pathways of colorful floor markings, for promoting the green spaces of the university and for facilitate walking in the campus. In the *Playful City* case study, a prototype of two 30-minute walking trails was designed. The first path led to the green spaces of the university whereas the second path led to the built facilities of the university. The studies conducted in phase 3 offered a set of scientifically-based design principles that were then projected in the *Playful' City* case study. Three in field studies were run. The purpose of this study was to see how colorful floor markings affected pedestrian crossing tasks, spontaneous walking patterns, and perceived pleasantness. Also, compare the impact of color designs placed in an urban versus a natural setting.

In these three studies, a combination of self-declared evaluations and objective measurements were used to assess the walkers' responses to the environment pre-post design interventions. These studies are presented in Part III of this thesis.

5.9 CONCLUSION

At the University of Lille, the *Playful City* case study employed an original approach to the design of urban walk-ability, by combining living lab approaches and experimental psychology methods. The goal was to see how cognitive tools may be used to enrich living labs methods and give valuable user's feedback from objective measurements and subjective evaluations.

The goal of the in-field studies was to demonstrate how cognitive tools may be used to quantify the subjective experience of the users. The key innovation was to propose that the use of wearable devices could offer valuable feedback to both the users and the stakeholders on the power of the natural and visual nudges of the environment to trigger spontaneous walking behaviours.

6

STUDIES 5-7: IN-FIELD MEASUREMENTS OF THE IMPACT OF COLOR WALKS ON WELL-BEING

In preparation for publication in: Frontiers in Psychology

TITLE: In-field Evaluations of the Impact of Colorful Floor Markings on Cognitive Load, Stress Levels and Perceived Pleasantness

Authors: Adamantia BATISTATOU, Florentin VANDEVILLE, Alan KRZYSTEK, Muriel GARCIN, Hugo SIX, Olivier JANIN, Yvonne DELEVOYE-TURRELL

6.1 INTRODUCTION

Urban environments are linked to stress (Matheson et al., 2006) and various mental illnesses (Galea et al., 2005b; Guite et al., 2006; Lederbogen et al., 2011b). The infrastructure of an urban environment plays an important role in the impact it has on its users (Handy et al., 2002). Urban environmental elements such as, visibility (Knöll et al., 2018) and building facades (Elsadek et al., 2019) are linked to higher physiological and psychological stress from the user's point of view. Crowded streets elicit negative emotions and behaviors, like stress and aggression. (Engelniederhammer et al., 2019), whereas the exposure to road traffic and noise causes physiological stress, expressed as hypertension (Bluhm et al., 2007).

On the other hand, green environments are linked to stress recovery (Chen et al., 2018; Dolling et al., 2017; Tyrväinen et al., 2014; Ulrich et al., 1991). The application of green elements in the built environment proves to have a positive impact on reducing the stress levels of its users (Bolten & Barbiero, 2018; Gillis & Gatersleben, 2015). Green elements such as, green wall facades are linked to lower stress compared to concrete wall facades (Elsadek et al., 2019). Implementations of tress(Lin et al., 2014) and grass (Huang et al., 2020) are associated with the restoration of negative moods and the reduction of stress levels, whereas the exposure to nature soundscapes (Alvarsson et al., 2010; Shu & Ma, 2020) were associated with physiological and psychological stress recovery. But it is not always possible to introduce nature sensory elements into the built environment, due to budget, climate and design constraints.

Yet, it is not clear whether the colors of an environment or its content play an important role in relieving stress (Michels et al., 2021). Is the color or the setting of a scene of nature that is beneficial to humans? Paint is an easy intervention in the urban design as it is ephemeral, non-invasive and low budget. Colorful floor marking is a design solution commonly used by city planners for re-zoning urban spaces and guide pedestrians. Elements such as colored lines, geometric shapes and ludic designs transform places for pop-up events and lead pedestrians to points of interest such as, sports facilities, museums and parks. However, the impact of this design strategy have rarely been evaluated, namely because of the absence of a methodology to collect objective measures.

This paper is focused on testing the restorative impact of colorful floor marking into the urban setting. Connected devices and numerical questionnaires were included in a pre-post design procedure. The question was specifically to assess whether color interventions in urban spaces can have a positive impact on the perceived pleasantness reported by the users, and on the objective physiological and psychological measures collected through a wearable device.

6.1.1 *Theory*

Understanding the impact of colorful design in stress recovery requires understanding the broader theoretical perspectives that explain stress environmental restoration. Research in restorative environments is mainly based on two complementary theories. The Stress Reduction Theory (SRT) (Ulrich et al., 1991) and the Attention Restoration Theory (ART) (Kaplan, 1992). The SRT theory is a pshyco-evolutionary theory that says that humans because they evolved in nature, are physiologically and psychologically better adapted to natural environments, compared to urban settings, whereas the ART theory is a psycho-functionalist and says that humans have an innate tendency to respond positively to nature. According to the ART, fascination plays a key role in restoration. Environments that enhance patterns that they do not require attentional effort have a positive impact to the mental fatigue of humans and therefore, to stress recuperation (Berto et al., 2008).Both theories agree that nature is more beneficial to humans than urban settings, but the former (SRT) links the environment with the physiological and affective responses of the user, while the latter (ART)links a setting primarily to the user's cognitive responses. (Berto, 2014).

To understand better this two main theories a clarification of the physiological and affective responses to stress, as well as the cognitive responses to stress is required. The psychological stress is depending on the Autonomic System (ANS), the automated stress-regulation system of the human body. It consists from the sympathetic and the parasympathetic system. The first one, triggers the fight-flight effect, whereas the second one, decreases the stress levels and activates the relaxation state. This two systems create allostasis in the human body to keep it stable through change (Brown et al., 2013). The sympathetic increase heart rate and decrease of the heart rate variability. The parasympathetic on the other hand,it decreases the heart rate and increases heart rate variability. Previous research indicates that parasympathetic activity is higher when the person is in a natural environment (Egorov et al., 2017b). How could colors in the urban environment impact the parasympathetic activity?

Affect is a broad term that includes different types of feelings that a person can have. These affects have five categories emotions, moods, attitudes, interpersonal stances and affective depositions. Affective reactions are showing the tendencies of moods and types of emotions regarding an experience even when the stimulation is low (Scherer, 2005).Previous research indicates that affective states are more positive towards natural environment compared to urban environments (Kinnafick & Thøgersen-Ntoumani, 2014). How could colors in the urban environment impact the affective state of the user?

Finally, Stress has an effect on cognition as demanding more cognitive effort, or attentional control from the subject. The cognitive load is related to the amount of attention allocated at a given time at a given task (Sweller, 1988), often referred to is as "cognitive effort" (Piolat et al., 2005). Stress increases cognitive load as it creates a dual-task where the subject needs to cope with the attentional demands of the task as well as the attentional demands of the environment (Stawski et al., 2006). Previous research indicates that cogntive load is lower when the person is in a natural environment than in an urban (Grassini et al., 2019). How could colors in the urban environment impact the cognitive load of the pedestrians?

6.1.2 *Colors impact spontaneous behavior*

Color psychology has demonstrated that colors can impact spontaneous motor behavior (Bazley et al., 2017). Colors can impact the spontaneous walking behavior of the user. The subjects walked faster when the red stimuli was presented compared to the presentation of the blue stimuli. (Meier et al., 2012). Also, colors have an impact on time-related parameters. For example, colors can influence perceived speed.Research indicated that athletes with red T-shirts were perceived as they run faster than those with blue T-shirts. (Mentzel et al., 2019). Also, colors were shown to influence the perceived duration of time.Red versus blue stimuli were used, with different saturation levels. The results showed that the subjects overestimated the duration of the blue stimuli(Thönes et al., 2018).

6.1.3 *Colors impact affective states*

Also colors can impact the affective state of the user (Bellizzi & Hite, 1992b; Valdez & Mehrabian, 1994). Colorful spaces have been associated with more positive affect than achromatic environments. Blue and green are correlated to positive emotional responses with the green to have the most positive scores (Kaya & Epps, 2004). On the other had, red can have positive or negative impact, as it sometimes works as as stimulating as well as distracting (Kuniecki et al., 2015). Also, findings suggest that environment color plays a significant role in stress perception. Students perceived was lower after exposure to the colors blue and pink, with the blue having stronger effect in the reduction of stress. Also, the students that were exposed in colorful room there significantly lower stress levels than the students that they were not exposed in colors (Elliot et al., 2007). Subjects in the red room had higher scores in the stress perception compared to green or white room conditions'(Kutchma, 2003a).

6.1.4 *Colors impact human physiology*

Colors can impact the physiology of the users (Jin et al., 2009). Red colors make the heart beat faster and increase the blood pressure were the blue correlates with lower heart rate (AL-Ayash et al., 2015). Also colors, can impact physiological arousal and skin conductance (Wilms & Oberfeld, 2018b) study tested 30 colors based in 3 hues (blue, green, red) and 3 saturation levels (low, medium, high) by using a LED panel. The results suggest that the arousal ratings increased from blue to green and from green to red for high and medium saturation levels. The average arousal rating was higher for chromatic colors with high saturation than those with medium or low saturation. Also, the arousal increased with brightness.

There are limited studies showing how environmental settings impact physiological and cognitive stress in real-time, outdoor experiments. Sensors that capture electrodermal activity (EDA) and heart rate (HR) in combination with subjective measurements are suggested to be the most reliable (Kondo et al., 2018b; Pykett et al., 2020).

Physiological stress is measured with the use of electordermal activity (EDA),in particularly, the phasic changes are brief sharp changes of EDA and they are good indicator of stress (Sparrow et al., 2020). The HR is also an indicator of stress as it is proven that HR increases during a stressing stimulus and decreases during the exposition to restorative environments (Ulrich et al., 1991).

The cognitive stress of the users is measured with the cognitive load, the slow changes of tonic phases of EDA. Stress has an effect on cognition as demanding more cognitive effort, or attentional control from the subject. The cognitive load is related to the amount of attention allocated at a given time at a given task (Sweller, 1988), often referred to is as "cognitive effort" (Piolat et al., 2005). Stress increases cognitive load as it creates a dual-task where the subject needs to cope with the attentional demands of the task as well as the attentional demands of the environment (Stawski et al., 2006).

Perceived stress from a psychological point of view is the individual's subjective opinion on how much stress he/she perceived during an experience (Cohen et al., 1983). The perceived stress in this study is measured with the use of positive valence. Research has shown that higher positive valence was correlated with lower perceived stress. The negative association that was found between positive valence and perceived stress was much lower than the positive correlation between negative valence and perceived stress (Lebois et al., 2016).

Building on the above evidence, we report data to assess whether colors can be used in urban environments to enhance the pleasure and well-being during spontaneous walking. We systematically evaluated the restorative effects of colors through the quantification of the changes in affective states, in perceived and physiological stress and in the cognitive load associated to the spontaneous behavioral of walking through the campus of the University of Lille (France). In the three studies presented, we hypothesized that colorful walking trails will have a positive effect on the psychological and physiological states of the users.

Our hypothesis is that colorful floor marking comparing to the environment without colorful floor marking will correlate with more positive affect, lower physiological and cognitive stress

Two walking trails were created for the purpose of this study. Each trial was two kilometers long crossing different areas of the university campus of Cité Scientifique (Lille University, France). The first walking trail was geared towards the green areas of the campus; The second trail led to the more constructed areas of the campus. A total of three experiments were conducted. In the first experiment, we examined the effects of colorful design interventions on the task of crossing roads. In the second experiment, we evaluated the psychological and physiological states of adults walking on a 30-minute walking trail towards the building facilities of the university before and after the implementation of design features. In the third experiment, we contrasted the users' experiences of walking through nature and through colorful urban designs in order to reveal the possible restorative power of colorful floor markings in old urban settings.

6.2 EXPERIMENT 1

6.2.1 *The effect of colorful cross roads on cognitive load and valence. Comparing colorful crossroads to white cross roads and to crossroads without floor marking*

Pedestrian behavior studies say that the sensation of seeking and stress can influence negatively a pedestrian's decision-making on road crossing (Rosenbloom, 2006). Crossing the road at a crossroad is a highly complex task that requires an efficient perceptual and cognitive process. One of the most important factors for the visual perception of a crossroad is colors and background contrast (Langham & Moberly, 2003). The perceptual factor can have an impact on the cognitive process when crossing a road particularly on the attention factors that are linked to the ability of a target to be easily identified (Ariane et al., 2007)

Also, colors correlate with the attention load of the user (Dzulkifli & Mustafar, 2013). Research has shown that colored multimedia presentations resulted in better attention than non-colored presentations (Farley & Grant, 1976). Furthermore, it is found that warm types of colors such as yellow, red, and orange have a greater effect on attention compared to the cool type of colors like brown and gray (Pan, 2010). Also, colors can be identified faster over other variables like shapes (MacKay & Ahmetzanov, 2005).

In this experiment, the impact of colors on the crossroads task is tested.

The hypothesis for this study was:

H1: More positive valence for color-design compared to white-line crossroads

H2: More positive valence for white-deign compared to white-line crossroads.

H3: Lower cognitive load for color-design compared to white-line crossroads

H4: Higher cognitive load will be needed for the white-design compared to white-line crossroads.

6.2.2 *Methods*

6.2.2.1 *Participants*

Thirty-four university staff members and students (18 females) aged 18+ (SD ± 11.13) years participated voluntarily in the study. Each of them received an information sheet and completed a written informed consent. Participants reported having a normal or corrected-to-normal vision and no deficiencies in terms of motor control. The protocol was registered by the ethical committee of the University of Lille (2019-328-S68) and with the CNIL (GED UnivLilleN1-201816).

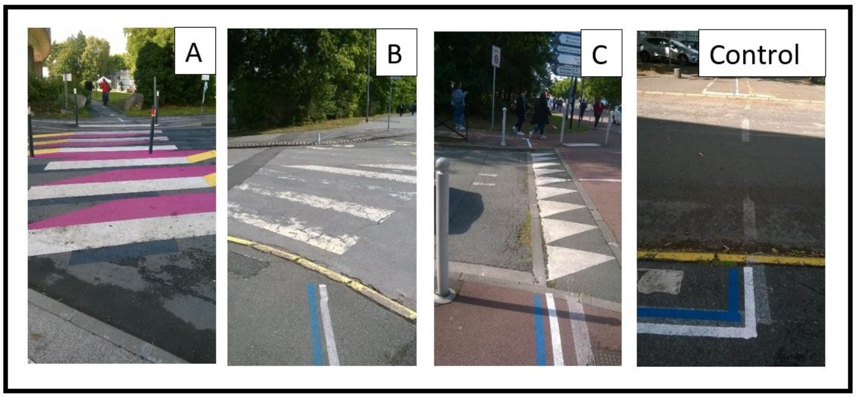
6.2.2.2 *Design*

The length of the trail was two km. The type of environment was a combination of build environment and organized nature. The experiments took place during day time from nine o'clock in the morning until five o'clock in the afternoon. The weather was sunny around 20 degrees Celsius. When the weather had big changes like rain and wind the experiments were postponed for another day.

Specific points were tagged on the trail for future analysis. Specifically, four crossing points were tagged and analyzed for this study. A colorful crossroad (A), a classic white lines crossroad (B), a white with triangles crossroad (C), and a crossroad with no floor marking (Control). Illustrations are provided in Figure 35.

Figure 35. A colorful crossroad (A), a classic white lines crossroad (B), a white with triangles crossroad (C), and a crossroad with no floor marking (Control).

Figure 35: Different designs of crossroads.



6.2.2.3 *Measures*

Objective and subjective measurements were recorded. In the present study, subjective experiences were collected by asking each participant to score, at 8 specific moments, the intensity and the pleasantness of her/his affective experience.

The Feeling and Affect Table to score Arousal and Appraisal (the FATAAL grid - Figure 3) is a 2-dimensional digital grid that is adapted from the Russell grid for Affective States (Russell et al., 1989). Implemented on mobile phones, it provides the means to collect from a distance the changes in affective experiences of a user throughout a natural task without the need of experimenter intervention.

For the objective measurements each participant was fitted with the NEOTROPE wearable watch. The AffectTag is a physiological affective analyzer. The smart-band provides a mobile solution to capture changes in a user's physiological responses during mobility through urban spaces(Sparrow et al., 2020). From this smart-band, affective measurements of cognitve load were computed in addition to the calculation of heart-rate frequency: Cognitive Load (CL): From EDA, this indicator reflects the amount of mental effort exerted and is calculated from the slow-moving tonic components of EDA at a given time frame.

A 60 second baseline was taken. The participant was asked to seat and do breathing exercises. The participant was asked to rapidly inhale and slowly exhale. This pattern of breathing creates parasympathetic activation and decrease sympathetic activation, that can be observed on EDA measurements (Cappo & Holmes, 1984). This breathing pattern activates the parasympathetic nervous system (Hirsch & Bishop, 1981; Moser M et al., 1994; Strauss-Blasche et al., 2000) as respiratory sinus arrhythmia (RSA) is influenced by breathe and is under the control of the parasympathetic nervous system.

A 60 second baseline for cognitive load was taken though mental calculation tasks of 25 increasingly difficult arithmetic calculations. Calculation tasks provided typical hormonal, physiological and electroencephalographic responses to cognitive stress especially under time pressure (Al-Shargie et al., 2016b). The calculation was additions and subtractions of 3 digits numbers (Dedovic et al., 2005b).

6.2.2.4 *Procedure*

The participants were invited to meet the experimenter at the main library of the university, wearing comfortable shoes. During this unique experimental session, the participant was invited to walk for 30 minutes following a predefined parkours that remained within the campus grounds. The trail was indicated with floor marking (a simple colored white line) that led the participant to engage in the three crossing points.

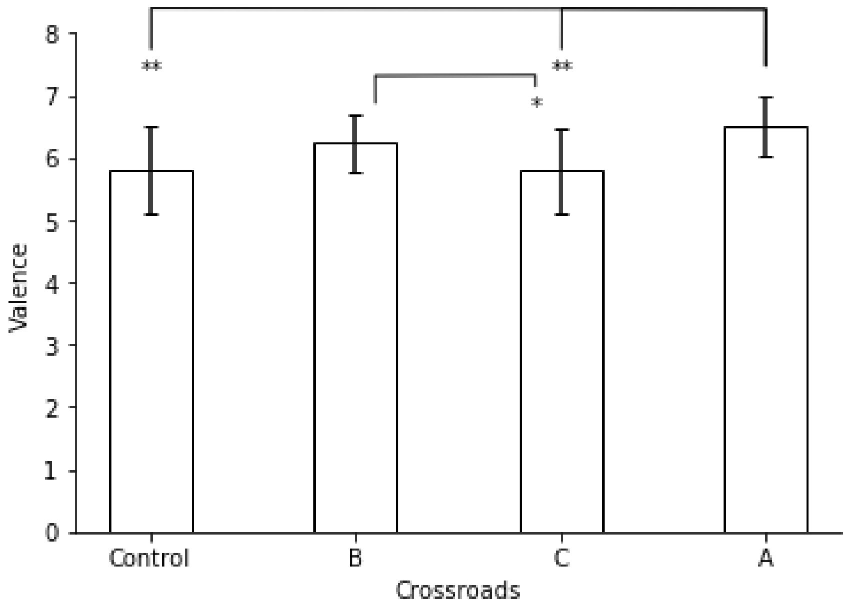
The participant was invited to engage in a gait pattern that was spontaneous and easy, to walk at her/his preferred pace. The experimenter walked by the participant's side and thus, adapted her/his pace to that of the participant. Discussions and all interactions were prohibited during the walk.

6.2.2.5 *Data processing and statistical analysis*

The results obtained at four types of crossroads were compared: color crossroad, white crossroad, white triangle design crossroad C.

Repeated Measures ANalyses Of VAriances (RM ANOVA) were carried out with the non-parametric Friedman test, as the normality conditions were not met. These analyses were performed with both personal code and algorithm adapted from the Python-based toolbox Homer2 (Massachusetts General Hospital, Boston, MA, USA). The significance level was set to an alpha of 0.01 and 0.05. *The star in the graph

Figure 36: Perceived pleasure depending on different designs of crossroads.



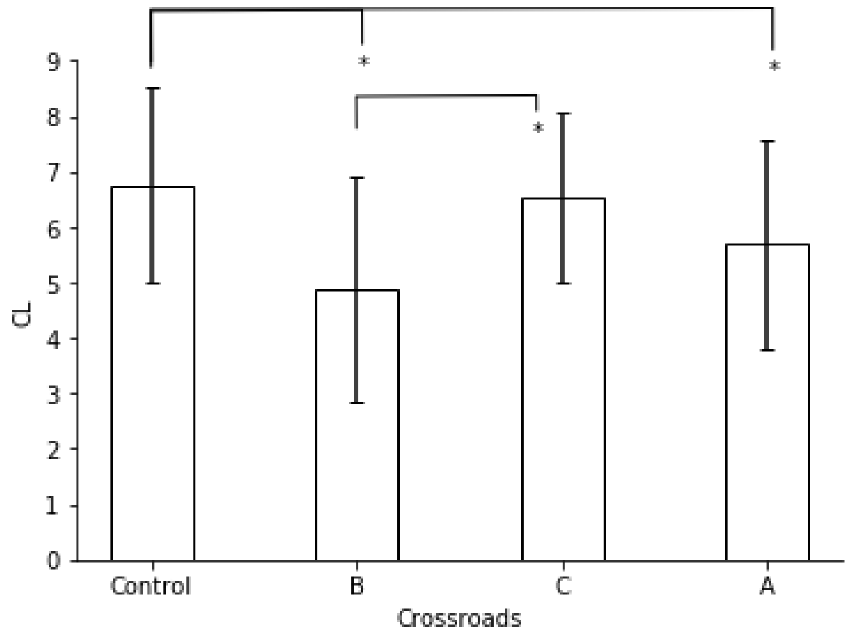
indicates the significant difference between the two conditions ($p < .05$). * The double star in the graph indicates the significant difference between the conditions ($p < .01$).

6.2.3 *Results*

The results indicate that, the users scored significant differences for perceived pleasure, between colorful crossroad (A) and control condition and between colorful crossroad (A) and crossroad (C). Also, it was found significant difference for perceived pleasure between white classical white lines crossroad (B) and white triangles crossroad (C).Figure 36 shows this trend.

The main effect cross road was significant for the perceived pleasure, $X^2(3)= 14.80$, $p= .002$, with larger scores in crossroad A ($M = 6.50$, $SD = 0.96$) than in crossroad C ($M = 5.79$, $SD = 1.34$) and control ($M = 5.79$, $SD = 1.41$). The Conover's Post hoc test confirmed significant differences between crossroad A and control ($p = .004$) and between crossroad A and crossroad C ($p=.001$). There was also a significant difference between crossroad B and crossroad C ($p = .03$). *The star in the graph indicates the significant difference between the two conditions ($p < .05$). * The double

Figure 37: Changes of cognitive load depending on different designs of crossroads.



star in the graph indicates the significant difference between the conditions ($p < .01$).See Figure 36

Moreover, the results indicate a significant difference for the cognitive load of the users. There was significant difference between colorful crossroad (A) and control condition, as well between classical white lines crossroad (B) and control. Also, there was a significant difference between classical white lines cross road (B) and white triangles crossroad (C). Figure 37 shows this trend.

The main effect Crossroad was significant for the cognitive load, $X^2(3) = 9.06$, $p = .03$, with lower scores in crossroad A (M = 5.69, SD = 3.78) and crossroad B (M = 4.87, SD = 4.06) than in crossroad C (M = 6.54, SD = 3.06) and control (M = 6.75, SD = 3.49). The Conover's Post hoc test confirmed significant differences between crossroad A and control ($p = .04$), between crossroad B and control ($p = .01$) and between crossroad B and crossroad C ($p = .049$). *The star in the graph indicates the significant difference between the two conditions ($p < .05$). See Figure 37

6.2.4 *Discussion*

From the previous results, we can indicate the first hypothesis was correct and that the colorful crossroads are perceived as more pleasant from the users compared to the white triangle designed crossroads and to the crossroads without floor marking. On the other hand, the users did not find the colorful crossroad significantly more pleasant than the white classical crossroad.

The second hypothesis was incorrect as the users found the white classical significantly more pleasant than the white triangle designed cross road.

The third hypothesis regarding the cognitive load of the users, was incorrect as of the colorful crossroads they do not facilitate the mental effort of the user to cross the street comparing to the crossroads with white classical floor marking. On the other hand, they do facilitate the mental effort that it is required for the users to cross the street when it is compared to the triangle designed cross roads and when it is compared to crossroads that they do not use floor marking.

Finally, the fourth hypothesis was correct. The users need more cognitive load for crossing the street with a triangle design crossroad than the classical white crossroad.

6.3 EXPERIMENT 2

6.3.1 *Measuring the impact of colorful interventions in the task of navigation. A 30 minutes walking trail towards the building facilities of the university.*

Colors can be influenced by the context that they are presented in. The color context theory (Elliot & Maier, 2012) suggests that the responses to color stimuli depends on the repeat patterns of colors and cultural messages, or that the biological color reposes are enhanced by cultural concepts. For example, the color red can be seen as attractive when it is seen on the face (blood flow modulation) but also when it is seen on clothes. On the other hand, the color blue can have a positive meaning on an object but negative on a piece of meat as it indicates that the meat is rotten (Meier et al., 2012).

Many times we refer to colors to symbolize emotions. For example, we say " I feel blue " to indicate that we are sad. Research tested the emotional associations of colors. Participants associated 20 emotion concepts, loading on valence, arousal, and power dimensions, with 12 colours presented as patches or terms. For all colors except color purple, high similarity in the pattern of associations was observed. Therefore it could be possible emotions to be linked colour concepts rather than particular perceptions or words of colour (Jonauskaite et al., 2020).

For this reason for this study we put the colorful floor marking in an urban playful context. Urban playful intervention defines the design or the re-utilization of the urban infrastructure that provides an alternative to adult pedestrian norms by inspiring happiness and playful interactions within the urban setting (Donoff, 2017). This was firstly done in order to distinguish the colorful floor marking from the floor marking for the drivers and also because previous research has shown that playful colorful floor marking can shape pedestrian behavior and that it suitable and safe for urban interventions (Nikolopoulou et al., 2015). Secondly, colorful playful intervention are the design tool that is used for transforming urban streetscapes in the urban settings (Pogačar & Šenk, 2018). Thirdly, playful design was used in order to put colors in a positive context. Play typically, it is phenomenologically associated with positive feelings (Bateson et al., 2013).

Colors can be influenced by lightness, chroma, and hue, but also of from factors such as distance and angle, amount and type of ambient light, colors combinations and background color and general environmental surroundings (Elliot, 2015). Also, personal preferences and past experience can play an important role tot he impact of the colors. Therefore, a range of colors and different color combination and shape were made in the design interventions.In this research we don't aim to compare the impact between colors, rather we compare the impact of colorful conditions versus non colorful conditions.

In this experiment, the impact of colors in an urban environment was tested. The effect of colorful floor marking in a navigation task inside the built environment of the campus site was examined. Our hypothesis was:

H1: More positive valence for the colorful condition than the control condition.

H2: Lower cognitive load for the colorful condition than the control condition.

6.3.2 *Methods*

6.3.2.1 *Participants*

Seventeen university staff members and students (9 females) aged 18+ (SD ± 10.4) years participated voluntarily in the study. Each of them received an information sheet and completed a written informed consent. Participants reported having a normal or corrected-to-normal vision and no deficiencies in terms of motor control. The protocol was registered by the ethical committee of the University of Lille (2019-328-S68) and with the CNIL (GED UnivLilleN1-201816).

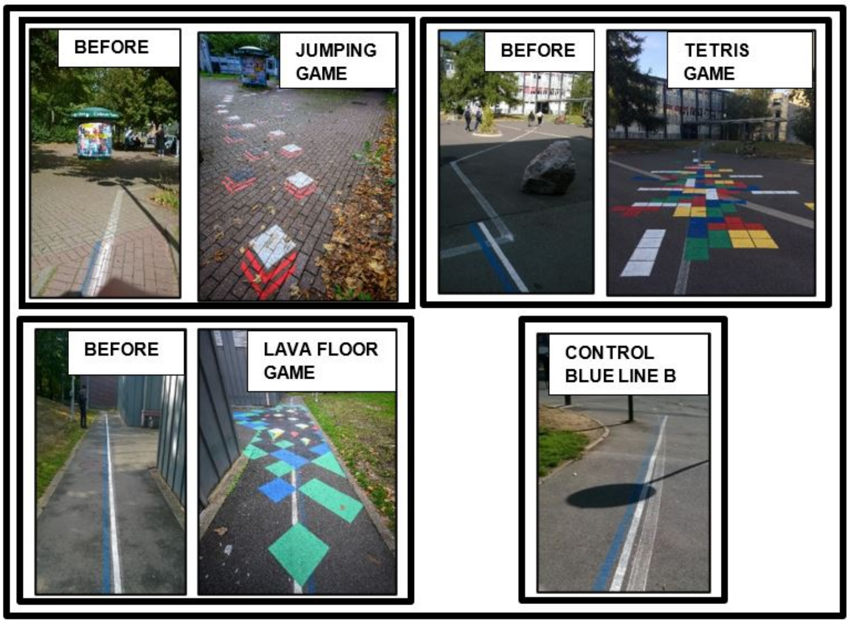
6.3.2.2 *Materials*

The length of the trail was two km. The type of environment was built environment. The experiments took place during day time from nine o'clock in the morning until five o'clock in the afternoon. The weather was sunny around 20 degrees Celsius. When the weather had important changes (like rain and wind) the experiments were postponed for another day.

Specific points were tagged on the trail for future analysis. The difference between and after the design intervention was examined. The design interventions that were implemented were a jumping game, a Tetris game, and a lava floor game. The blue line that was painted before session 1 and session 2 was used as a control. Illustrations are provided in Figure 38.

Figure 38. Jumping game (location before and after intervention). Tetris Game (location before and after intervention). Lava floor game (location before and after

Figure 38: Experiment1.Before and after different colorful designs interventions.



intervention). The blue line was used as a control and it was the same during the session 1 and 2.

6.3.2.3 *Procedure*

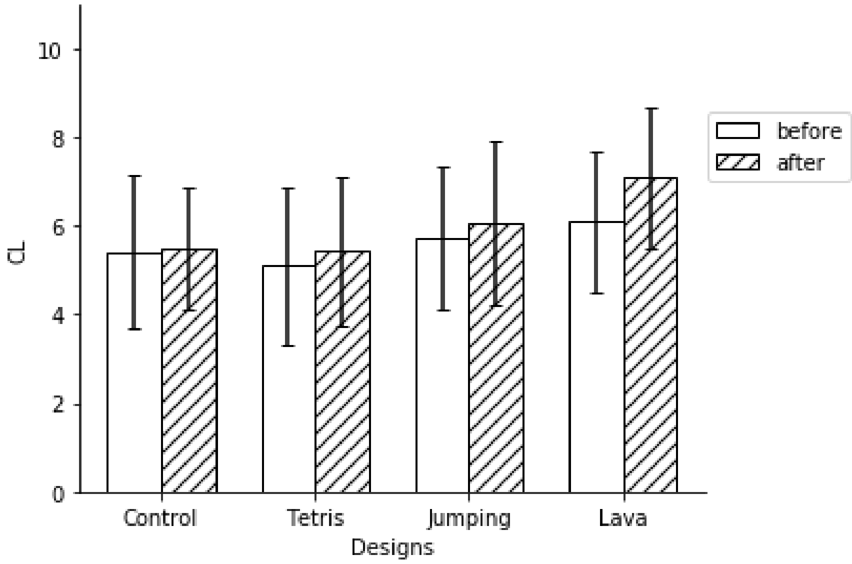
The design was similar to Experiment 1, with the difference that measurements were made before and after the installations. The second phase of the measurements took place two weeks after the first phase. The weather and the time of the meetings were the same as the Experiment 1.

6.3.2.4 *Data processing and statistical analysis*

The results obtained comparing the tags (Jumping game,Tetris, Lava floor and control) before and after interventions, a between subjects' analysis was made

Repeated Measures ANalyses Of VAriances (RM ANOVA) were carried out with the non-parametric Wilcoxon test, as the normality conditions were not met. These analyses were performed with both personal code and algorithm adapted from the Python-based toolbox Homer2 (Massachusetts General Hospital, Boston, MA, USA). The significance level was set to an alpha of 0.01 and 0.05. *The star in the graph

Figure 39: Changes of cognitive load before and after different colorful designs interventions



indicates the significant difference between the two conditions (p < .05). * The double star in the graph indicates the significant difference between the conditions (p < .01).

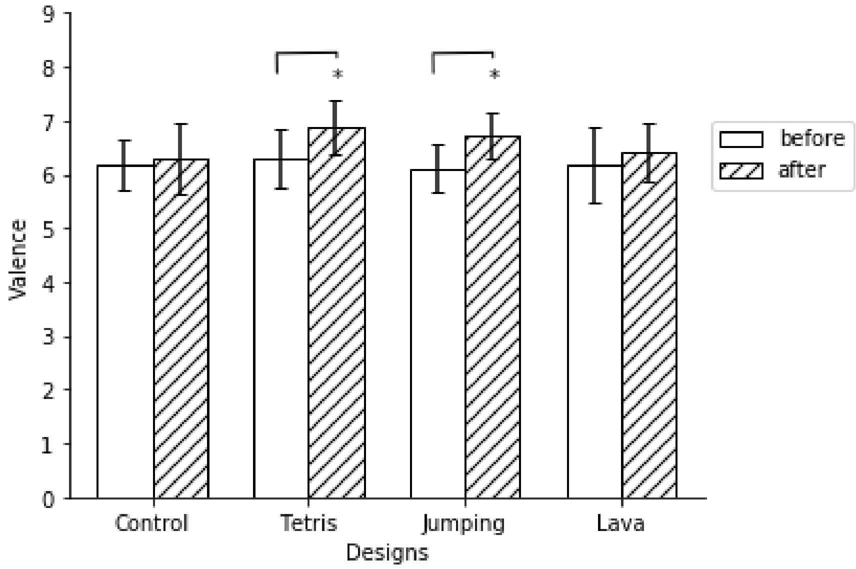
6.3.3 *Results*

For the cognitive load of the users, no significant differences were found comparing before and after intervention condition. However, users scored significant perceived pleasure for the intervention condition Tetris comparing this tag to before the intervention condition. Significant differences for the intervention condition Jumping game comparing this tag to before the intervention condition.Figure 39 and Figure 40 shows this trend.

Note. The main effect of intervention was non significant for cognitive load for none of the tags: blueline B (T= 0.08 ; p= .94), Tetris (T= 0.27 ; p= .79), jumping (T= 0.34 ; p= .74) and Lava (T= 1.13 ; p= .27). See Figure 39.

Note. The main effect of intervention was significant for perceived pleasure for some tags : Tetris (W= 12.5 ; p= .001) with higher scores after intervention (M= 6.88 ; SD= 0.99) compared to before (M= 6.29 ; SD= 1.10), jumping (W= 21 ; p= .004) with higher scores after intervention (M= 6.71 ; SD= 0.85) compared to before (M= 6.12 ;

Figure 40: Changes of perceived pleasure before and after different colorful designs interventions.



SD= 0.93). There is no significant difference for blueline B (W= 65; p = .29) and lava (W= 63; p= .25). See Figure 40.

6.3.4 *Discussion*

From the previous results, we can indicate that our first hypothesis was correct and that the design intervention was perceived as more pleasant from the users for the interventions Tetris and Jumping game. However, the Lava game was not perceived more pleasant than the control condition. Probably due to the not clear goal of the game.

Moreover, our second hypothesis was incorrect as the design condition did not facilitate the mental effort of the user to navigate inside the campus. Probably because the users new already very well the area and there were not crossroads in the walking trail.

6.4 Experiment 3

6.4.1 *Restoration effect of colors. Comparing colorful interventions to the build environment and nature*

Although a few studies have used EDA to measure restoration in different environmental setting (Chrisinger & King, 2018a), few have focused on how different types of landscape, might affect the density of the peak amplitudes of EDA. Studies have found a relationship between the amplitude of SCRs and the strength of sympathetic activation (Fowles, 1980; Pribram & McGuinness, 1975). Although several distinct activation systems (Boucsein, 2012; Pribram & McGuinness, 1975) have been described, the sympathetic systems has been reported to be specifically implicated in the modulation of the affective states during field experiments (Sparrow et al., 2020). Characterized by quick phasic changes with high amplitudes that are similar to reflex responses, we used EDA indicators (Emotional Density and Emotional Power) to reveal the impact of color design on the frequency and the strength of affective reactions, respectively.

The third experiment compared the colored and not colored urban structured to nature. In this study, the effect of colorful floor marking before and after design intervention was tested. Also, different locations were compared between them. The location nature, urban and design interventions.

Our Hypothesis for this study was:

H1: Higher perceived pleasantness for colorful interventions

H2: Higher perceived pleasantness for nature vs building environment

H3: Equal perceived pleasantness for nature and colorful interventions

H4: Lower cognitive load for colorful interventions vs building environment

6.4.2 *Methods*

6.4.2.1 *Participants*

Twenty- five university staff members and students (14 females) aged 18+ (SD ± 11.13) years participated voluntarily in the study. Each of them received an information sheet and completed a written informed consent. Participants reported having a normal or corrected-to-normal vision and no deficiencies in terms of motor control. The protocol was registered by the ethical committee of the University of Lille (2019-328-S68) and with the CNIL (GED UnivLilleN1-201816).

6.4.2.2 *Materials*

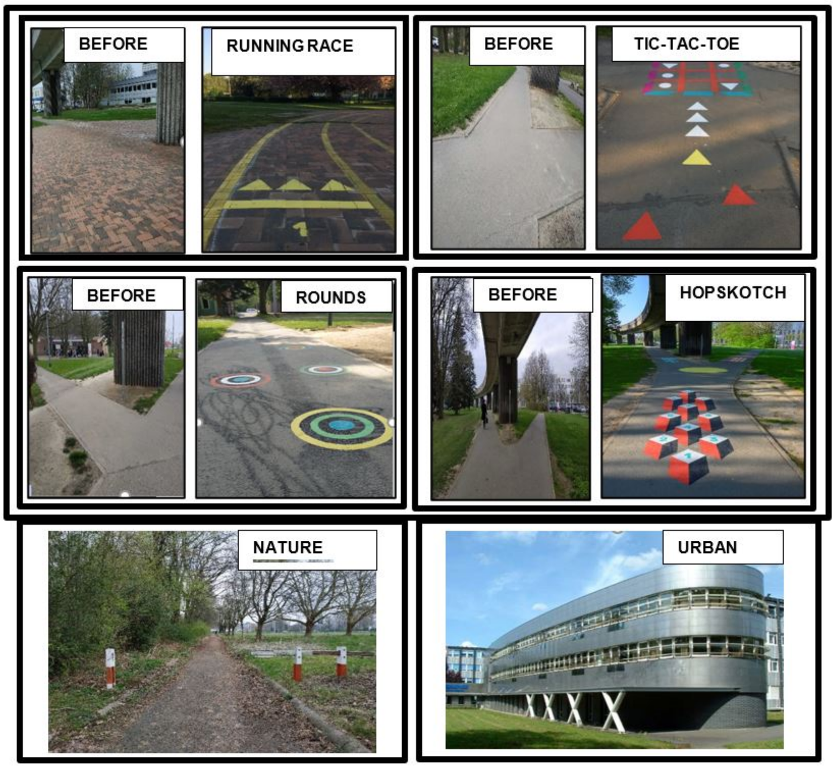
The length of the trail was two km. The type of environment was built environment and organized nature. The experiments took place during day time from nine o'clock in the morning until five o'clock in the afternoon. The weather was sunny around 20 degrees Celsius. When the weather had big changes like rain and wind the experiments were postponed for another day.

Specific points were tagged on the trail for future analysis. The difference between after the design intervention was examined and the different locations were compared between them. The design interventions that were implemented were a running game, a TIC-TAC-TOE game, colorful rounds, and a hopscotch game. Measurements were taken also for the tag nature and the tag urban. Illustrations are provided in Figure 41.

Figure 41 Running Race (location before and after intervention). Tic-tac-toe Game (location before and after intervention). Colorful Rounds (location before and after intervention). Hopscotch game (location before and after intervention). Location Nature, Location Urban.

The design was similar to Experiment 2. The weather and the time of the meetings were the same as the Experiment 1 and 2.With the use of the Affect Tag solution the following complementary measurements were made.

Figure 41: Experiment2.Before and after different colorful designs interventions..



Emotional Power (EP): From EDA, this indicator reflects the strength of emotional reactions and is calculated using the amplitudes of the EDA phasic peaks at a given time frame. Emotional Density (ED): From EDA, this indicator reflects the frequency of emotional reactions and is calculated using the number of EDA phasic peaks at a given time frame.

6.4.2.3 *Procedure*

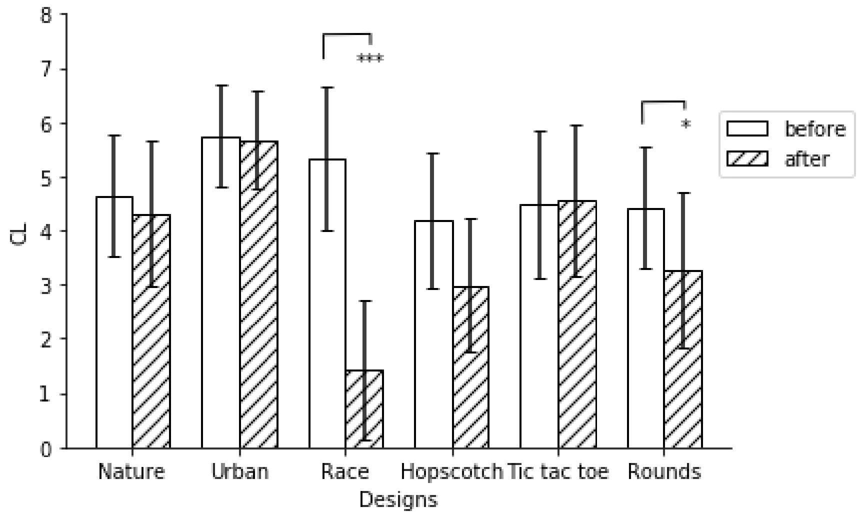
The design and procedure were similar to the Experiment 2.

6.4.2.4 *Data processing and statistical analysis*

The results obtained comparing the tags (Running Race, Tic-tac-toe Game,Colorful Rounds Jumping game,Hopscotch gameTetris, Location Nature, Location Urban) before and after interventions, a between subjects' analysis was made

Repeated Measures ANalyses Of VAriances (RM ANOVA) were carried out with the non-parametric Friedman test, as the normality conditions were not met. These

Figure 42: Changes of cognitive load comparing session 1 to session 2.



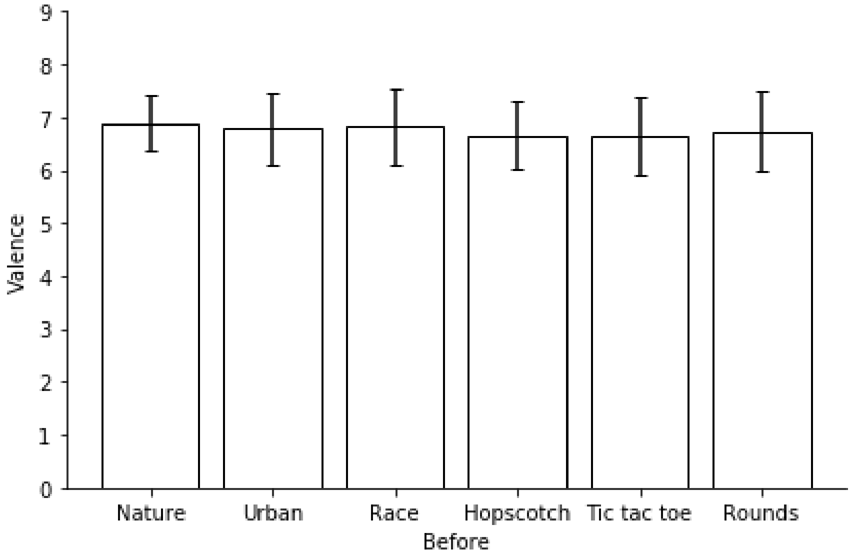
analyses were performed with both personal code and algorithm adapted from the Python-based toolbox Homer2 (Massachusetts General Hospital, Boston, MA, USA). The significance level was set to an alpha of 0.01 and 0.05. *The star in the graph indicates the significant difference between the two conditions ($p < .05$). * The double star in the graph indicates the significant difference between the conditions ($p < .01$).

6.4.3 *Results*

The users scored significant differences for the cognitive load for the intervention Running Race and for the colorful Rounds comparing before and after intervention. Also, significant perceived pleasure was found for the intervention condition Running Race comparing this tag to before the intervention. Figure 42 and Figure 43shows this trend.

The main effect of intervention was significant for cognitive load for Race (T= -5.76 ; $p < .001$) with lower scores after intervention (M= 1.42 ; SD= 2.55) compared to before intervention (M=5.33 ; SD= 2.67), Rounds (W= 82, SD= .03) with lower scores after intervention (M= 3.25 ; SD= 2.87) compared to before intervention (M=4.42 ; SD= 2.25). There is no difference after intervention for Nature (W= 142 ; p= .29),

Figure 43: Changes of perceived pleasure comparing session 1 to session 2.



Urban (T= -0.24 ; p= .41), Hopscotch (T= -1.69 ; p= .052) and Tic tac toe (T= 0.10 ; p= .92).See Figure 42

The main effect of intervention was significant was significant for perceived pleasure for Race (W= 83.5 ; p= .03) with lower scores after intervention (M= 6.70 ; SD= 0.89) compared to before intervention (M=6.83 ; SD= 1.43). There is no difference after intervention for Nature (W= 92 ; p= .06), Urban (W= 109.5 ; p= .15), Hopscotch (W= 103 ; p= .11), Tic tac toe (W= 97 ; p= .08) and Rounds (W= 102.5 ; p= .11). See Figure 43

Comparing the different locations, there was no significant difference for the cognitive load of the users before the intervention condition. Although, significant differences for the cognitive load was mentioned comparing the urban setting with the colorful designs. Figure 44 and Figure 45 shows this trend.

No significant differences were observed for the cognitive load when comparing nature, urban and urban setting before colorful intervention.See Figure 44

The friedman test showed that there is a significant difference between tags for cognitive load after the intervention (X^2 (16)= 40.44 ; $p < .001$). The Conover's Post hoc test confirmed significant differences between Urban for the following tags: Race ($p < .001$), Hopscotch ($p < .001$) and Rounds (p= .002). We also had a difference

Figure 44: Changes of cognitive load comparing different locations between them before colorful interventions.

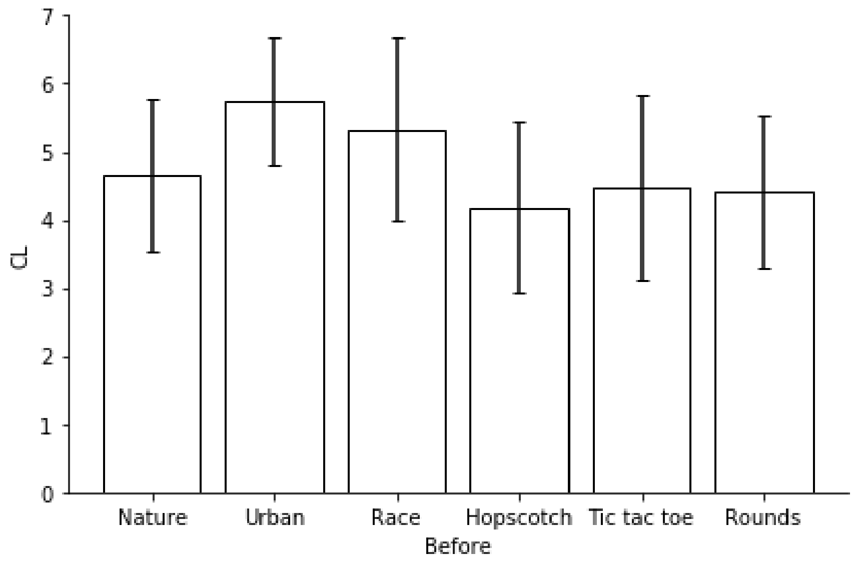


Figure 45: Changes of cognitive load comparing different locations between them after colorful interventions.

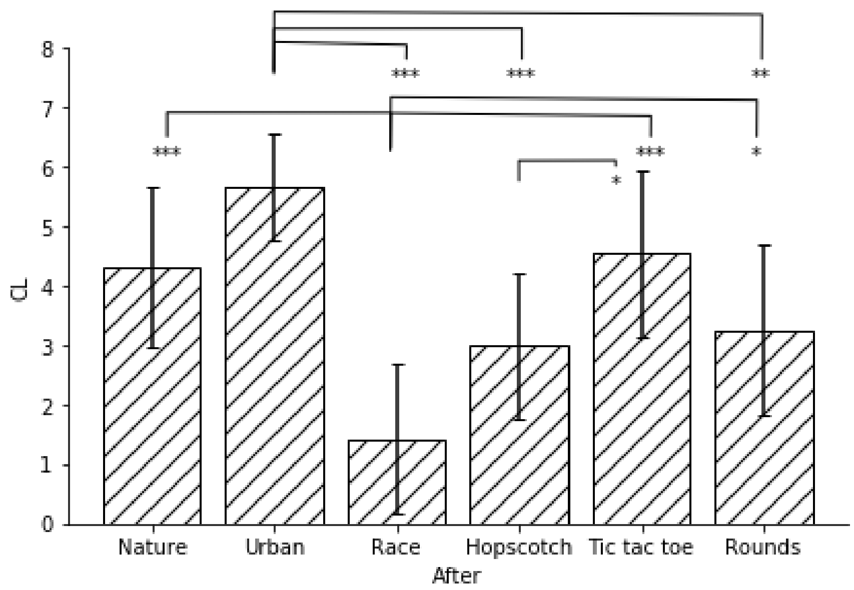
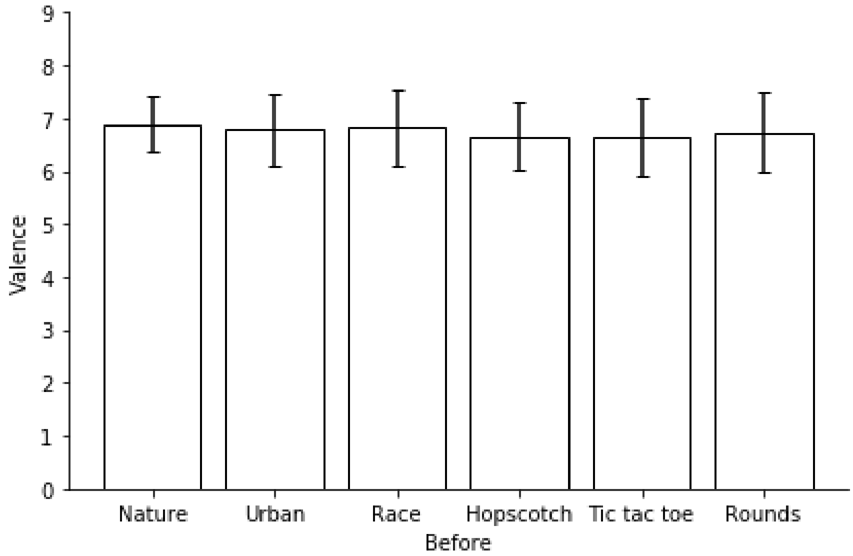


Figure 46: Changes of perceived pleasure comparing different locations between them before colorful interventions.



between Race and Tic tac toe ($p < .001$), Race and Rounds (p= .01), Nature and Race ($p < .001$) and Hopscotch and Tic tac toe (p= .02). See Figure 45

No significant differences for pleasure comparing nature, urban and urban setting before colorful intervention. Also, no significant differences for pleasure comparing nature, urban and urban setting after colorful intervention.Figure 46 and Figure 47 shows this trend.

The friedman test confirmed that there is no difference between tags for perceived pleasure before the intervention ($X^2(16)= 6.60$; p= .25).See Figure 46

The friedman test confirmed that there is no difference between tags for perceived pleasure after the intervention ($X^2(16)= 8.47$; p= .13). See Figure 47

Users scored no significant differences for emotional power comparing nature, urban and urban setting before colorful intervention. However, significant differences were found for perceived pleasure comparing nature, urban and urban setting after colorful intervention. Figure 48 and Figure 49 shows this trend.

There was no significant difference before the intervention (X^2 (16) = 6.25; p= .28). See Figure 48

The friedman test showed that there is a significant difference between tags for emotional power after the intervention (X^2 (16)= 27.74 ; $p < .001$). The Conover's Post

Figure 47: Changes of perceived valence comparing different locations between them after colorful interventions.

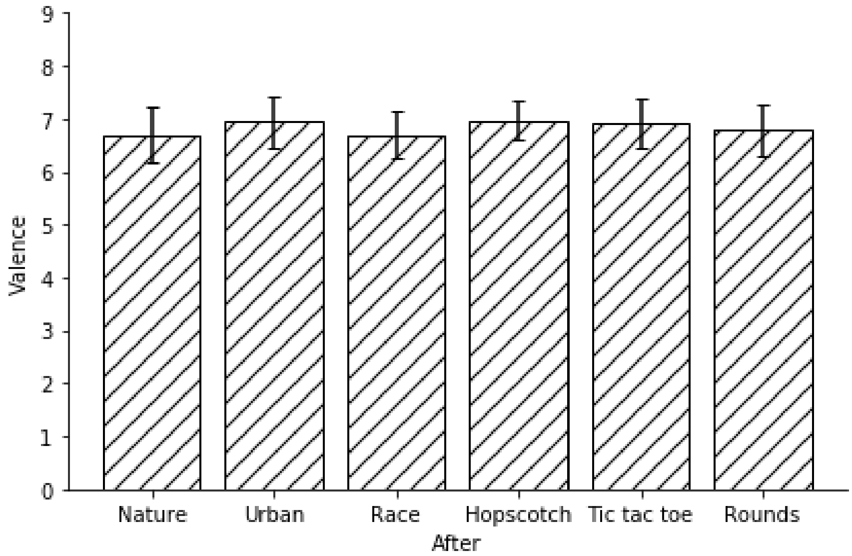


Figure 48: Changes of emotional power comparing different locations between them before colorful interventions.

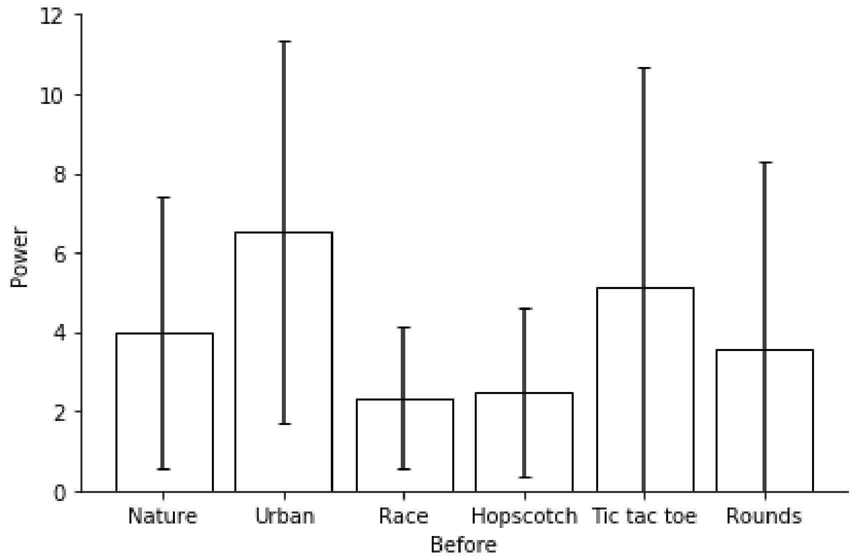
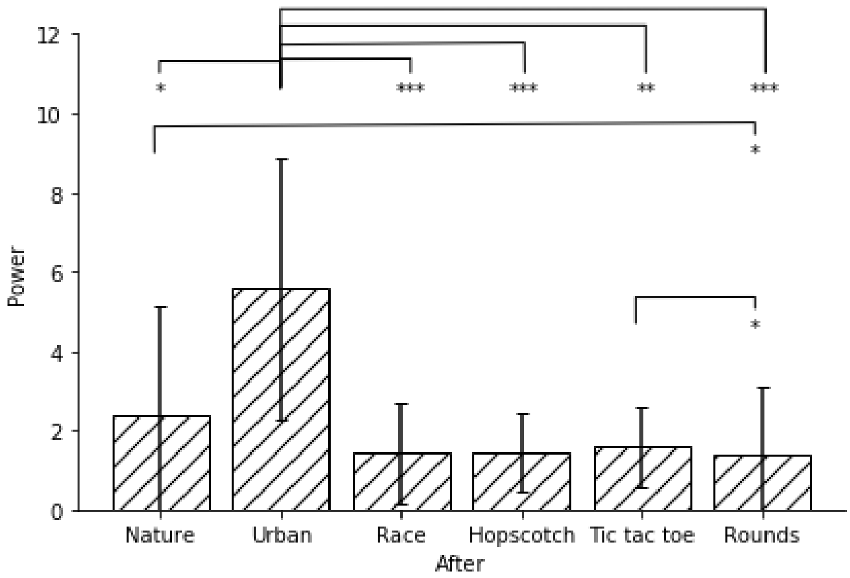


Figure 49: Changes of emotional power comparing different locations between them after colorful interventions.



hoc test confirmed significant differences between Urban and all the other tags : Nature ($p= .02$), Race ($p < .001$), Hopscotch ($p < .001$), Tic tac toe ($p= .006$) and Rounds ($p < .001$). The post hoc test also showed a significant difference between Nature and Rounds ($p= .02$) and between Tic tac toe and Rounds ($p= .04$. See Figure 49

Users scored significant differences for emotional density comparing urban and urban setting before colorful intervention. Also, significant differences were recorded for emotional density comparing urban and urban setting after colorful intervention. Figure 50 and Figure 51 shows this trend.

The friedman test showed that there is a significant difference between tags for emotional density before the intervention (X^2 (16)= 11.80 ; $p= .04$). The Conover's Post hoc test confirmed significant differences in the first session between Urban and Race ($p= .01$) and between Urban and Hopscotch ($p= .003$). See Figure 50

The friedman test showed that there is a significant difference between tags for emotional density after the intervention (X^2 (16)= 11.17 ; $p= .048$). The Conover's Post hoc test confirmed significant differences in the first session between Urban and Race ($p=.002$) and between Urban and Hopscotch ($p= .02$). See Figure 14 and 15. See Figure 51

Figure 50: Changes of emotional density comparing different locations between them after colorful interventions.

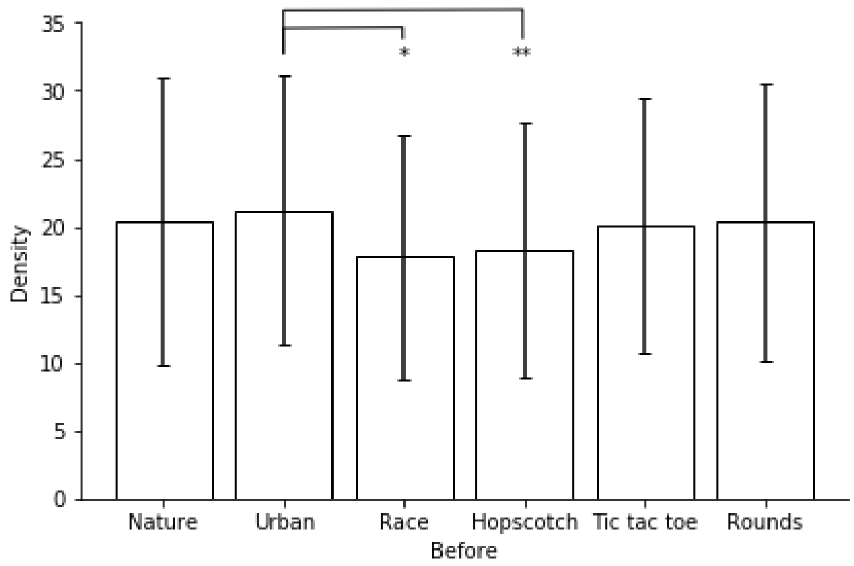
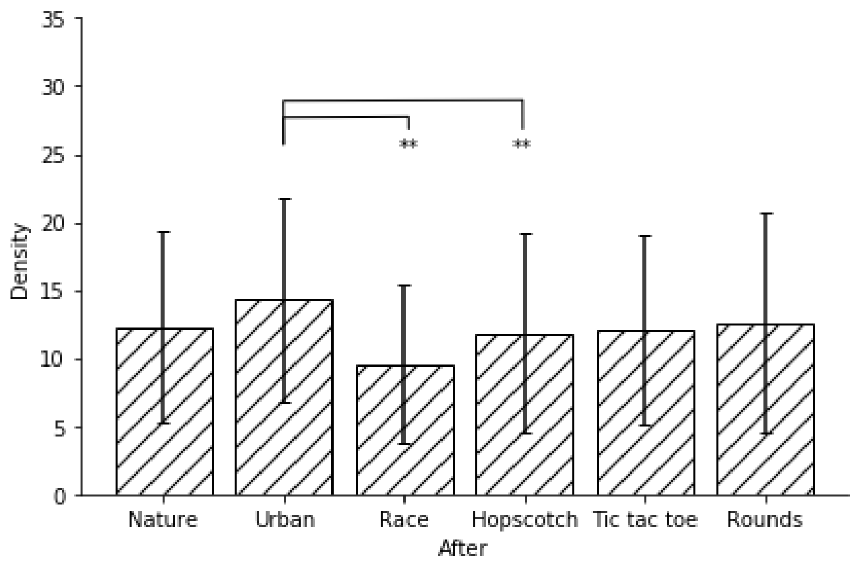


Figure 51: Changes of emotional density comparing different locations between them after colorful interventions.



6.4.4 *Discussion*

Comparing the tags before and after design intervention, we can indicate that our first hypothesis, higher perceived pleasure for design interventions was correct, only for the design intervention running race.

Our second hypothesis the cognitive load, the mental effort of the user, would be lower for colorful interventions comparing before and after design intervention, was correct for the design Running Race and for the design colorful Rounds and not for the other design interventions. Maybe it was due to the fact that the designs with significant differences was in decision points and in crossroads. Therefore, the design could facilitate the decision of the user which direction to take.

Comparing the tags between them we can see that the cognitive load, the mental effort of the user, was lower comparing the urban condition with the design interventions. The results show that the running race intervention was the design that facilitated the navigation of the user the most, comparing to the other design interventions. It is interesting to note that the running race intervention was on a crossroads with five possible exits. Therefore, is logical that a design intervention that guides the user at that location had a great impact on the cognitive load of the walker.

Moreover, comparing the tags between them we can see a significant difference in the emotional power of the user, the strength of the user's emotional reactions. For these results, we can state that after the design interventions the users are more relaxed, less alarmed about the environment comparing to the urban condition.

As well as, to the emotional density of the user, the frequency of the emotional reactions of the user. There were some differences in the urban locations between them, that the design failed to have an impact on the relationships of these locations.

6.4.5 *Discussion*

This paper aimed at improving the pedestrian experience in an urban environment, with the use of colorful floor marking.Using a wearable device, we presented a pre-post method that can be used in real life environments to demonstrate when and how colorful floor markings can impact the spontaneous behavior of pedestrians. The main results indicate that firstly, colorful crossroads are perceived as more pleasant and more easy to cross from the users compared to the white triangle designed crossroads and for crossroads with absence of floor marking. Secondly, users found more pleasant the designs that were easy to decode compared to more abstract designs. Thirdly, the users would navigate more easily, with less mental effort, in the urban setting and through "decisions points" such as, multi exit crossroads when the design solutions were displayed. Finally, the users were less aroused while walking in colorful design setting compared to the urban setting.

The first experiment compared the impact of colorful markings in crossroads. The results indicate that the users experience more positive valence compared to the classic white crossroad and to the control (absence of floor marking). Also, less cognitive load was found for the user of the colorful crossroad compared to the control. This could build up with the previous research mentioned that colors can have an impact on human physiology and that floor marking can shape pedestrian behavior. As the floor marking was colorful may it was easier to be spotted from the user and facilitate their navigation.

The third experiment compared the colored and not colored urban structured to nature. The cognitive load was significantly lower for the running race game and for the colorful rounds interventions. This game was placed in a round intersection with five possible exits. Therefore, the floor marking facilitates the navigation of the user by leading the walker to the desirable exit. Similarly, the intervention colorful rounds were placed in a decision point where the user should decide if he would continue straight or go left towards the green environment of the university. Also, the emotional power, the emotional activation of the user it was lower after the design conditions compared to the urban environment. Therefore, the results could state that the user was more relaxed and less alarmed while exposed in the colorful design conditions.

All in all, floor marking looks to be a promising tool for non-temporary, low-cost medium from transforming urban spaces. Research has shown the different positive impacts of nature, it is interesting to look closer to the different elements of the natural environment and how they could be implemented to the urban space. Nature is a colorful landscape that changes during the different seasons. Therefore, colors could be a component that has a positive impact on the users and needs to be further tested.

6.5 LIMITATIONS

The limitations of this research, are firstly on the selection and production of the stimuli, the number of designs. Based on previous research that states that floor marking in public space can shape pedestrian behavior: make the users walk slower, change their trajectory and make them stop walking (Nikolopoulou et al., 2015). However, more trials and designs clusters would be needed to be tested in order to understand which design elements are efficient and understand why.

Secondly, the difficulty to control all the variables. It is hard to control all the variables in ecological experiments like the weather, the luminosity, and the pedestrian and car traffic density. Therefore, it would be useful to reproduce the experiments in a more controlled environment and compare them with the ecological results of this study.

Thirdly, the number of participants it was a limitation for this study. The measurements were taken individually for each participant, in contrast to the most ecological experiments that test groups of people together. This was done to avoid social bias from our experiments. Therefore, due to the limitations of time and the physical effort that was demanded by the researchers, it was not possible to have more participants for our experiments. The duration of each experiment was no longer than one month for controlling the weather as much as possible. The time schedule for each experiment was one week of testing (before the design interventions), two weeks of design implementation and one week of testing (after the design interventions). Also, the experimenter was needing to walk every time with the subject and each researcher was not doing more than 3 hours walking per day.

6.6 CONCLUSION

From the above, we can conclude that colorful floor marking may have an impact on the psychology and physiology of the users. City planners and stakeholders should now consider reactivating urban spaces with the use of colors, implementation of nature and playful interventions. Cities should consider the support and prioritize the transformation of public space for promoting the well-being and the physical activity of their citizens. Through sensorial transformations with colorful and playful intervention, the users can be led to gyms, parks and cultural centers, or to the local stores to bust and support the local producers.

These findings support to continue to develop methods of evaluations of urban design interventions by testing and measuring prototypes. Design guidance for urban interventions, methods of research and evaluation is a field that needs to be developed and considered in the city policies. How design can affect the mental effort, reduce stress and trigger spontaneous walking of the users are crucial questions that need to be answered for creating human-centered cities that promote the well-being of the users. Research tools can now be used outside the laboratory walls to test and measure what works and what does not. Temporary interventions are low-cost approaches that are easy to implement, and they can give valuable insights into how and which urban design elements influence spontaneous behavior.

6.6.1 *Acknowledgments*

Special thanks Studio Lebleu, La Condition Publique - Roubaix and to Mme M. Garcin and her team from the University Department of Sport Facilities for the coordination of this implementation phase.

7

STUDY 4: DESIGNS AND WELL BEING IN THE SCHOOL YARDS

Authors: Adamantia BATISTATOU

This work was funded by Ombelliscience

7.1 INTRODUCTION

A body of research indicates that children in school can experience high levels of stress. For example, aggressive behaviors such as bullying (Andreou et al., 2021), expectations such as student achievement (Manns et al., 2021) racism and negative teacher behavior (Ray, 2007) are some of the sources of stress for primary school children. The schoolyard is a valuable framework for promoting children's resilience to stress (Kelz et al., 2015). Several studies have redesigned schoolyards to enchase students' recovery from stress. Most studies have shown that implementing nature such as trees and flowers has a positive impact on student stress levels (Chawla et al., 2014; Paddle & Gilliland, 2016). In addition, the location of the school appears to have an impact on the stress level of students (Kirubasankar et al., 2021). Research shows that urban students are more exposed to stressors such as noise, pollution, artificial light, small unnatural spaces or unhealthy transport routes. Participatory research is an umbrella term that covers a range of methodological approaches and techniques, which aim for an active collaboration between researchers and participants (Bergold Thomas, 2012). In participatory research, participants take an active role in the research process. The participants themselves identify the research question, the hypothesis, they generate data and they analyze and even contribute for interpreting on the information generated. Participatory research can choose to involve participants at all stages of the research or at specific stages of the research depending on its objectives. Participatory design with children can positively contribute to the health and well-being of children. Participation improves children's sense of competence, self-esteem and communication skills (**kinn**; Bečević & Dahlstedt, 2021). Also, through participation of children in urban planning, they enrich their sense of community and their attachment to places (Jansson et al., 2018). Finally, participation in urban planning, make the users to be more likely responsible when using these places (Chawla & Derr, 2012).

7.2 CASE STUDY

The Case study of this research program took place at the school Ampere, Lille. The Ampere school is situated in the urban center of the city and it is categorized as a school with a population with socioeconomic difficulties. The school started a program to renovate the schoolyard. The objectives of the school's stakeholders were firstly, to identify the stress zones of the schoolyard and secondly, to generate design solutions that promote the well-being of the students during yard breaks. The intervention took place for two weeks at a class of second grade. The goal of this pilot study was to create a participative research protocol for the school for a future use.

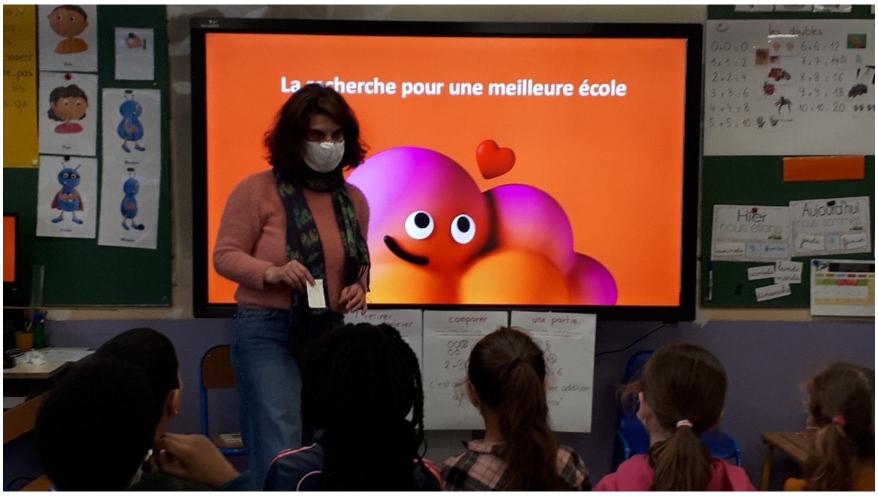
7.3 OVERVIEW OF THE RESEARCH PROJECT

A mixed research methodology was used for this case study. Tools from experimental psychology and participatory design were used. The research intervention was held in three phases. The first phase is the information phase. This step aimed to inform the students about the project, its objectives and their role in it. The second phase is the observation phase. This step aimed to observe the use of the schoolyard by the students. The third phase is the evaluation phase. This step consisted of assessing the problematic areas of the schoolyard. Finally, the fourth phase is the ideation phase. This phase aimed to create design solutions with students to improve the quality of life in the schoolyard.

The aim of this phase was to inform the students about the research project. A short presentation in the form of a discussion, adapted to the age of the students, enabled the following questions to be discussed.

- What is stress?
- What is environmental psychology?
- How can the environment influence the well-being of populations?
- How can the design of the schoolyard affect the physical and emotional well-being of students?
- How can participatory research help to rethink the schoolyard to promote student well-being?

Figure 52: Presentation and discussion with students.



7.5 PHASE 2A- OBSERVATION

The aim of this phase was to observe how the pupils use the space of the schoolyard. The participatory photo method (PPM) is a research method used to understand from the user's point of view how the user interprets, understands and navigates in his environment (Dennis Jr et al., 2009). This method is suitable for children because it is fun, tangible and easy to use (Aitken & Wingate, 1993). In addition, it is a silent tool that offers the possibility even for young children to express their point of view. To apply PPM, students gave the researcher a tour to introduce him to schoolyard spaces that are meaningful to them (Clark, 2011). The researcher for facilitating the guided tour asked the children the following open-ended questions.

- Where you go to relax?
- Where you go to play?
- Which places in the schoolyard are your favorite?
- Which places in the schoolyard are the worst?
- Is there a place you never go or that you are afraid of?

A total of 11 students (5 girls and 6 boys) aged 7 years participated in the study. The photos were taken with the use of mobile phones.Researchers and students walked around the schoolyard. The research asked the students the questions described above. The children told the researcher which places should be photographed and why. See Figure53

7.6 PHASE 2B – CATEGORIZATION

The aim of this phase was for the children to classify the photos into three predefined categories Play, Relax, Hostile/Never Go. Affordance theory says that different elements of the environment prompt the user to take different actions. The user will see this different invitation to act based on their prior physical and mental knowledge, beliefs and abilities (Davids et al., 2016; Gibson, 1979b). In the categorization phase, students' subjective feelings related to schoolyard space were explored (YILMAZ et al., 2017).

Figure 53: Children demonstrate how they play with the tree in the schoolyard.

The materials used for the categorization of the photographic documentation were the photographs printed in A4 and stickers in three colors.

The photos were displayed on the school wall. Students had to classify the photos into one of the three categories Invitation to Play, Relaxation or Hostile / Never Go. To do this, they had to paste the colored sticker corresponding to each category. See Figure 54

Figure 54: Children discuss and vote for the subjective affordances of the photos.

Figure 55: Photos categorized in Play, Relax, Hostile/ Never Go.

From the above results, the following affective map was created with the use of emoticons See Figure 56.

Figure 56: Affective map of the schoolyard from children's point of view.

The purpose of this phase was to study the perceived restoration value of the schoolyard. Attention Restoration Theory (Kaplan, 1992) says that an environment is restorative when it contains the following four characteristics. Fascination, being away, extension, compatibility. Fascination is the ability of an environment to arouse people's curiosity. Being away is when a place can take the user's mind away from everyday life and worry. Extension when it is easy to navigate the environment and identify the information it provides. Compatibility is when an environment meets a person's preferences and goals.

A total of 11 students (5 girls and 6 boys) aged 7 years participated in this study. A child-friendly version of the Perceived Restoration Scale (PRS) (Pasini et al., 2014) adapted to children (Bagot, 2004) was translated into French and used. To adapt the task to the age of the subjects, the responses were a Linkert scale using emoticons (Bruggers et al., 2018). The children after the break in the yard returned to the classroom and completed the questionnaire. The researcher asked the questions and the children circled the emoticon that represented their response.

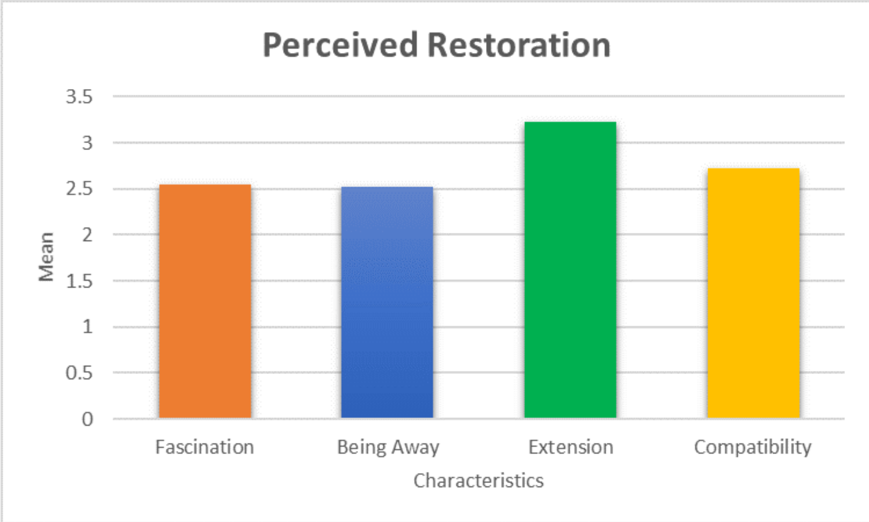
The Friedman test was used to asses the effects of different characteristics of the environment Fascination, Being Away, Extension and Compatibility.To compare the mean differences between boys and girls for each category, paired t-tests were performed with Student's test. These analyses were conducted with JASP Software and the significance level was set to an alpha of 0.05.

7.7.1 *Results*

The results indicated a significant difference for the Extension category compared to the categories Fascination and Being Away. Figure 57

Note. Extension was significant higher compared to Fascination, $X^2(3)= 8.208$, p= .042, with higher scores in Fascination (M = 3.272, SD = 1.009) than in Combability (M = 2.727, SD = 0.984), Fascination (M = 2.545, SD = 0.753) and Being Away (M

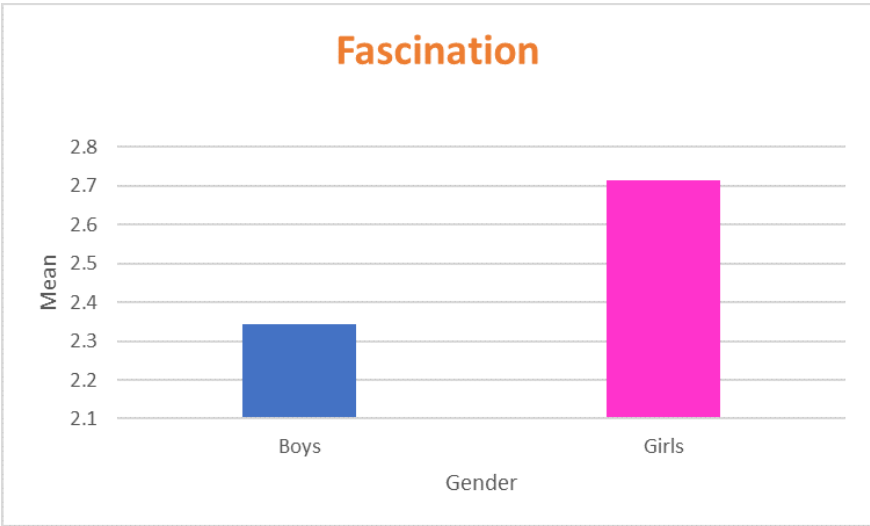
Figure 57: Perceived Restoration.



= 2.521, SD = 0.659). The Conover's Post hoc test confirmed significant differences between Extend and Fascination (p = .012) and between Extend and Being Away (p = .039).

For the Fascination category, the results indicate that there is a significant difference due to gender.

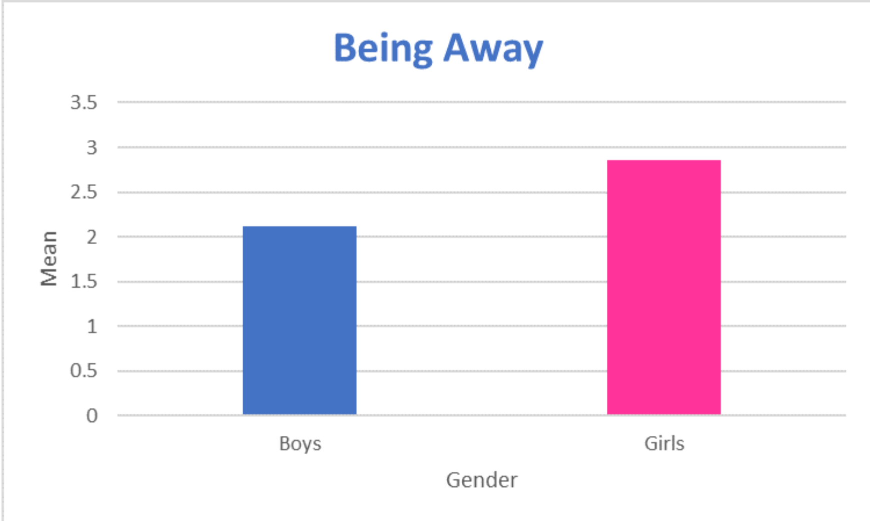
Figure 58: Fascination.



Note. Fascination significant different due to gender $X^2(3)= 5$, $p= .479$, with lower scores in Boys (M = 2.343, SD = 0.748) than Girls (M = 2.714, SD = 0.706).

For the Being Away category, the results indicate that there is not a significant difference due to gender.

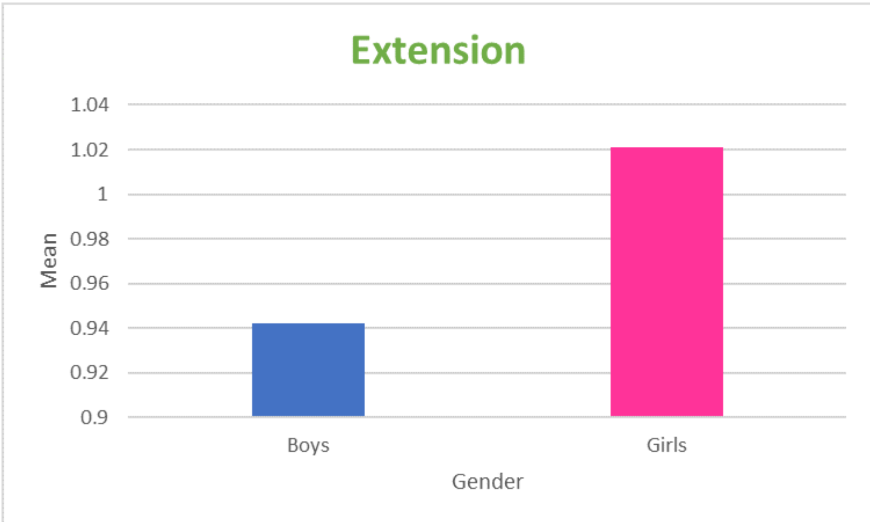
Figure 59: Fascination.



Note. Being Away was not significant different due to gender $X^2(3)= 5$, $p= .074$, with lower scores in Boys (M = 2.113, SD = 0.353) than Girls (M = 2.861, SD = 0.662).

For the Extension category, the results indicate that there is a significant difference due to gender.

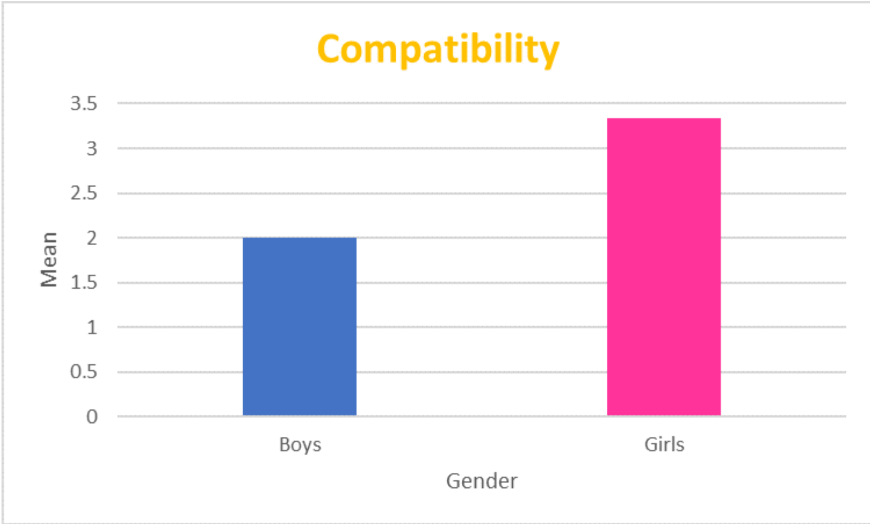
Figure 60: Extention.



Note. Extend significant different due to gender $X^2(3)= 5$, $p= .57$, with lower scores in Boys (M = 3.000, SD = 0.949) than Girls (M = 3.417, SD = 1.021).

For the Compatibility category, the results indicate that there is a significant difference due to gender.

Figure 61: Compatibility.



Note. Combability significant different due to gender $X^2(3)= 5$, $p= .038$, with lower scores in Boys ($M = 2.000$, $SD = 0.548$) than Girls ($M = 3.333$, $SD = 0.816$).

7.7.2 *Conclusion*

From the above, we can conclude that the schoolyard is best rated by students for its ability of Extension (easy to navigate), compared to the characteristics of Fascination (awake curiosity) and Being Away (drift away from their everyday life and worries).

In addition, boys find the schoolyard less interesting (fascination) than girls. Boys find the schoolyard less easy to navigate (Extension) than girls. Boys find the schoolyard less compatible with their preferences and interests than (Compatibility) than girls. In contrast, the schoolyard has the same impact on students in terms of the ability to let go of one's mind (Being Away).

The aim of this phase was to generate design solutions to enhance the schoolyard restoration effect. The design proposals were made by the students. In this phase the collage method was used (Gerstenblatt, 2013). A collective collage was made with the aim of creating the ideal courtyard from the students' point of view. To inspire students and facilitate ideas, images of design solutions from other schools around the world have been provided. The design solutions presented to the students were selected based on two criteria. First, to reinforce the three criteria of fascination, well-being, and compatibility that had lower review rates when it comes to the perceived restoration of the schoolyard. Second, the design solutions to be inexpensive and easy to make by students and teachers themselves.

A total of 12 Students (7 girls and 5 boys), aged 7 years participated in this study.A map of the schoolyard was used as a support, taken from google maps. The photos with the design solutions were taken from the internet. Paper and colors for drawing were used.

The results of the previous phase were explained to the students. The students formed 4 groups. Each group was to discuss and collaborate to choose their group's design proposals. Students could choose until three photos from the design proposals selected by the researcher and draw, as well, their own design idea. After selecting the models, each group pasted their proposals on the collective card explaining why they chose these models. See Figure62. The pictures were categorized into three predefined themes Fascination, Being Away, Extension, Compatibility.

7.8.1 *Outcome*

Issues such as loneliness, lack of facilities for intense team play and lack of space for relaxation are the main elements that emerged from the analysis of the collage activity. From the children's drawings, facilities such as swings, slides, trampolines and parkours were the design solutions most requested. From the designs proposed

Figure 62: Children glue their design propositions on the map.

by the researcher, design solutions that strengthen communication and bonding between students, such us the bench of friendship, and written messages on trees, were the most preferred. Finally, design solutions that enhance relaxation areas, such as a relaxation tent, were a request from the students. See Figure 63

Figure 63: Collage-design propositions by the students.

7.8.2 *Design propositions*

The design proposals are intended to reinforce the four characteristics (fascination, being away, extension and compatibility) that an environment must include in order

Figure 64: Design solution, friendship bench. « I choose the friendship bench because I have no friends » Comment stated by a girl.

Figure 65: Design solution, slide and trampoline, drawing, boy

to have a nurturing effect on the user, according to Kaplan's attention restoration theory and the preferences and needs of the students. Also, the design proposals, aimed to low cost and easy to make interventions. To enhance the element of fascination, children's craft design solutions are offered as they can be easily renewed during the school year to maintain the novelty effect. To reinforce the element of being away, design solutions favoring imaginative play and the creation of suitable relaxation spaces are proposed. To reinforce the element of compatibility, design solutions that promote physically active group play and promote social relationships between students were selected. Finally, to facilitate the meaning of extension design solutions using color codes and floor marking were used. From the above the following design propositions were emerged:

The kids liked the idea of putting their crafts in the backyard. They thought it would be a great activity to prepare surprises and messages for other students, as well as to discover surprises that other classes have prepared for them. See Figure 66

Figure 66: Design solution, for Fascination

The children paid particular attention to design which allowed them to create their own personal relaxation space. As mentioned above, children do not have enough places to sit and rest and at the same time to protect themselves from weather conditions like us the sun, wind and cold. Imaginative play, such as play "we are at camping" or "we are family" games and reading, has been reported by students as a way to relax emotionally and physically. See Figure 67

Children expressed their need for intense physical play as well as the lack of facilities for this purpose in the school yard. The students reported feeling lonely during

Figure 67: Design solution for being away

the break in the school yard. Creating zones for group play could enhance the socialization of students. See Figure 68

Figure 68: Design solution for Compatibility

Floor marking for creating zones of group play and relaxation. Floor marking is easy to apply and low cost. The color codes can be easily understood and identified by the students. See Figure 69

Figure 69: Design solution for extension

7.9 CONCLUSION

The results show that students can easily navigate (extension) in the schoolyard and find the information they are looking. On the contrary, the feeling of curiosity (fascination) and drift away from everyday worries (being away) is significant lower in relation to the ability of the students to navigate in the schoolyard.

In addition, the results show that the schoolyard is more suited to the needs and preferences of girls than boys. The boys gave lower scores in the yard on fascination, extension and compatibility. In contrast, both genders gave the same score for the element being away.

Problems such as loneliness, lack of facilities for intense team play, and lack of space to relax are the main elements that emerged. According to the children's drawings, installations such as swings, slides, trampolines and parkours were the most requested design solutions. Among the designs offered by the researcher, design solutions that strengthen communication and bonding between students, like us the Friendship Bench, and messages written on trees, were the most preferred. Finally, design solutions that enhance relaxation areas, such as a relaxation tent, were a request from the students.

7.10 DISCUSSION

The participation of children in research offers the opportunity to understand their needs and personal experience, in order to provide essential solutions to improve their quality of life. Children with this research approach are not just participants but co-researchers. This research approach needs absolutely to be based on the rights of children to participate voluntarily in the research process.

7.10.1 *Limitations*

This research had limits due to the covid restrictions. We were not able to apply the design interventions and do pre-post measurements. In the future, for a more complete research protocol, application and test of the different design proposals is need it.

Another limitation is the number of participants, which weakens the statistical power of the protocol. But the goal of this process was the realization of a pre-test before a protocol that could be generalized to all school students. Finally, one limitation was the group of people who committed to overseeing this project. In a future school-based participatory research project, the active participation of teachers and students is needed to understand the problems of schoolyard life and find meaningful design solutions.

7.10.2 *Future Research*

Future research for this project should first create and implement the design solutions at the prototype stage to assess their impact before and after implementation. Collaboration with pupils and teachers could also be set up in order to better adapt the questionnaires to the objectives of the project and to the age of the children. The implementation phase of this work could not be done because of the COVID-19 lockdowns. Future collaborative work is in discussion.

Part IV

GENERAL DISCUSSION

8

GENERAL DISCUSSION

8.1 INTRODUCTION

According to Gibson, the environment in which we live is made of potential invitations to act. He termed these possibilities affordances.

"The environment's affordances are what it offers the animal, what it provides or furnishes, for good or ill." (Gibson, 1979a).

Affordances can be positive (e.g., an apple) or negative depending (e.g., a rotten apple) on our perceptions and abilities (Gibson, 1977).

Affordances are thought to be present in the environment as distinctive elements from the user or a group of users (Kyttä et al., 2003). For example, a designer would design a bench with the goal to invite the user to sit on it. The city offers these urban elements that are distinct from the use, designing the objects as a function of utilisabity but not of emotional or affective states of the desire . An adult user when seeing this bench would probably see the invitation to sit. On the other hand, a child user, that is less conformed, could see the invitation to sit but also, to stand on it and jump.

In user experience design, research indicates that the aesthetics of a product will affect the engagement and the action perception of the user (Van Vugt et al., 2006). For example, if a user perceives an artifact of a virtual environment as helpful and aesthetically beautiful, she/he will be more willing to use it than an artifact that is not enhanced with positive valence. The concept of affective affordances explains the fact that the different artifacts of the environment such as, e.g., colors, music, odors - can not only generate cognitive motor responses but also affective responses (Caravà & Scorolli, 2020). This "affective load" can impact a user behavior by creating affective nudges depending on the individual's perception and past experiences. Thus, affordances can be generators of the interaction process between human and the environment. Furthermore, affective affordances can be generators of the engagement process, between human and its environment (Jensen & Pedersen, 2016). However, Gibson only describes the human-environment interaction in terms of the human's action possibilities within it. Indeed, the Gibson's theory does not describe the emotional interaction of this relationship and how it might impact final behavioural decisions. The emotional states that emerge from the human-environment interaction will determine the call to action, which the user will choose to accept and follow. Russel has stated that an affective state as how the physical environment influences emotion and behaviors and actions of humans (Russel, 1989). Hence, certain environment can impact positively or negatively the emotional and especially the en-grained affective state of the use.

There are evidence that green and natural environments can have a positive effect on people.Less psychological stress (Berto, 2014), physiological stress (Triguero-Mas et al., 2017), amelioration of mood and stress restoration greater when walking in nature environments compared to urban environments (Gidlow et al., 2016) and better cognitive function (Berman et al., 2008).On the other hand, urban setting is lucking these positive effects(Bluhm et al., 2007).My work, consisted in creating censorial nudges, low-cost design interventions that guide behavior, to validate their impact on human experiences and to use psychology testing, to promote walking.

The Theory of affordances says that humans have an embodied perception of the environment and that the environment constantly is presenting them a variety of artifacts that lead to possible behaviors, inviting them to act. However, cognitive psychology has proposed that simply looking an object can generate automatic action motor planning towards that object (Nazir et al., 2017) and generate affective responses (Murphy & Zajonc, 1993), the feelings that a person has when confronted with an object of attitude, that will impact their action tendencies.

Humans are always effectively engaged within an environment (Withagen, 2018) as it is the only way to experience a place. People, especially in our technological society, constantly shape their private and professional spaces to suit their practical and emotional needs (Krueger & Colombetti, 2018). We decorate our living room, put on music or dim the lights in order to organise an emotional space that suits us. From this point of view, the positive affordances involve perception and movement resulting in fascination and pleasure, whereas negative affordances generate stress and avoidance (Kyttä et al., 2003). Therefore, city planners need to focus their attention in constructing affective places that promote walking. What I propose in my thesis is a methodology to measure these affects with the use of cognitive psychological methods.

Playful City employed an original approach to the design of urban walkability by combining living lab approaches and experimental psychological methodology. The overall goal was to quantify the impact of colorful interventions, projected within an urban environment, on the affective and cognitive states of users. My research indicated firstly, the important relationship between the built environment and the walking experience. Second, the effectiveness of cognitive experimental tools for the evaluation of urban design interventions. Third, the importance of living laboratories to promote walkable cities.

8.2 OUR FINDINGS

Overall, results confirmed the power of colorful designs impact the behavior of the walkers. Specifically, color can induce feelings and or the perception of some affordances in users.

In Study 1, gaze behaviour and facial thermal responses to 32 colour patches were measured. The aim of this research was to select colours to target populations that differ in motivation profiles for spontaneous walking. Results indicated that for all profiles, red was the most salient. However, preferences differed as a function of profile types with: PSY preferring shades of green and pastel, PHY preferring strong reds and black color patches; APP preferring blue and bright yellows. These preferences predicted specific patterns of facial temperature changes as a function of motivation profile.

In Study 2, perceived restoratives and perceived stress levels of multi-image colourful sidewalks were measured, through an online experiment. The results indicated that colorful roads scored more positive valence and higher arousal ratings than the absence of colors. Red and green had stronger impact on perceived affective states than the color blue. Nevertheless, compared to the control environment, all colorful interventions were perceived as more restorative, associated to a feeling of fascination.

In Study 3, gaze behaviour and affective states of pedestrians were measured in six different design scenarios, through virtual reality. The results indicated that participants walked slower, experienced more perceived pleasure and fixated more often areas of interest when walking in an environment augmented with colorful designs. These beneficial effects on the user were stronger in urban environments, suggesting that the restorative phenomenon of nature may be partly related to the presence of colorful patterns.

These studies offered a set of scientifically-based design principles that were then projected in the Study 4, compared the impact of colorful markings on crossroads. Study 5, tested the impact of color lines and colorful painted patterns on spontaneous walking and perceived pleasantness of walking through campus. Finally, study compared the impact of color designs placed in an urban and in a nature environment. Overall, results confirmed the colorful designs decrease cognitive load and increase perceived pleasure in walkers in the urban setting.

In particular, colours can evoke emotions and can be used to signify the existence of certain affordances in space. In user experience design, colors and design patterns are consistently used to guide their users. For example, in websites and applications, red is often used in buttons that must be clicked when the user wants to indicate a negative answer and green when the user wants to indicate a positive answer. In western culture red is mostly related to danger, passion and anger whether the green color is mostly related to nature,to health or to sustainability. Although that each person or cultural groups can have individual meanings or preferences for each color the general "mood" of colors has already being strongly defined by our culture and the natural environment. Therefore, colorful interventions can be used to enhance walking experience.

8.3 FUTURE RESEARCH

In this thesis, we answered the question of how colorful interventions versus no colorful interventions impact the affective and cognitive states of walkers. Future participatory research in collaboration with artists and users of the city of Lille, aims to study the impact color's and design properties on walkers. Different patterns of design, color's contrast, and density, as well as the level of complexity of the designs will be examined.

Also we demonstrated that VR is a powerful tool to answer questions about censorial environments and nudging. It is a low cost, controlled environment, suitable for testing design scenarios before implement them in the real space. However, in our research we did not define the level of immersion of the user in the VR setting. More immersive stimulative environment for walking needs to be constructed.Future project aims to test different elements that could enhance pedestrian immersion in the VR setting. How the different elements of the environment (e.g., temperature, odors and environmental complexity) or mode of walking in the VR space, could impact the affective and cognitive states of walkers.

Finally, in our study, the floor marking intervention was not enough long and dense because of our budget capacities. Also only the ground floor was tested and not other places such us testing interventions on the eye-level of the pedestrians. Future research will aim at working with architecture department to analyse the spatial space of the implementation of the designs and controlling the size analogy of the designs.

Because it was implemented on the campus, our studies included a homogeneous sample of participants. Living Labs outside of the campus with the support of the city and of the private companies could help the conduction of research with more diverse samples of participants.

8.4 GENERAL CONCLUSION

In this research project for answering the question of how to quantify positive walking experience, we propose: First to use online experiments, with the use of surveys to test the general concept idea, second to use virtual reality to test the functionality of the designs, by including the use of eye tracking and third to do field experiments,with the use of wrist bands for physiological measurements, to test the designs in a real life context, in order to refine the final design solution.

This thesis points out that we need to research further the use of colors in the cities and how they could help to improve place restoration.As color design is a solution that is more economical,feasible, and effective compared to other design approaches. Furthermore, this thesis demonstrates how temporary interventions and low-cost, simple-to-implement approaches can be used in applied research for urban sustainability .

The findings reported from our field experiments reinforce the importance of applied research, embodied within a social innovation process such as in Living labs. With a co-design approach, with citizens, shop owners, researchers and city planners we could repair our cities and make city life better.

Overall, this dissertation makes several important contributions on measuring how the built environment impacts pedestrian experience. With the use of mobile research tools, we were able to go outside the laboratory walls to test and measure what works and what does not. This thesis propose to test at a small scale temporary design scenarios and after evaluation identify the most suitable design scenario to apply it at a big scale for restoring an urban area. This work offers new avenues towards the conception and the evaluation of urban design, with the use of the process demonstrated in this thesis, urban planners could identify and restore stressful areas of the city.

Part V

SECTION EN FRANÇAIS

9

SECTION EN FRANÇAIS

9.1 INTRODUCTION

« Peut-on bien vivre en ville ? » c'est une des questions posées aujourd'hui aux designers urbains qui doivent imaginer les villes de demain.

Le concept de Playful city s'est fondée sur une collaboration active entre les étudiants, les citoyens, les acteurs de la ville et les chercheurs de l'Université de Lille pour proposer une planification urbaine, intégrant les nouvelles technologies et la gamification sociale. Mon travail de recherche vise spécifiquement à évaluer, à améliorer et à terme, à valider cette planification urbaine centrée sur l'humain. Projet pluridisciplinaire de nature, mon travail de recherche vise à utiliser les outils de la psychologie expérimentale et des neurosciences pour créer des outils utiles et utilisables par les designers urbains. En m'inspirant de mon expérience en tant que designer UX (désigner pour tout ce qui concerne l'Expérience Utilisateur), mes créations offriront à la Métropole Européenne de Lille (MEL) des environnements sensoriels nouveaux et surprenants, pour promouvoir l'envie de marcher.

9.2 DESIGN URBAIN - BIEN-ÊTRE - MOBILITÉ DOUCE

La mobilité douce, comme la marche, améliore l'humeur, combat l'obésité et agit comme prévention de nombreuses maladies chroniques. Néanmoins, le mode de vie sédentaire s'installe comme norme dans nos sociétés modernes. L'organisation mondiale de la santé recommande 30 minutes de marche modérée par jour. Toutefois, les citoyens ne suivent pas cette recommandation. La question au départ de mon projet de thèse était donc de savoir comment concevoir des villes pour motiver et engager les citoyens dans une mobilité spontanée au quotidien, afin d'améliorer bien-être psychologique, physique et émotionnel.

Les espaces verts, comme les parcs et les forêts, les aires de jeux affectent positivement nos décisions à s'engager dans une séance d'activité physique. Ces résultats peuvent être traduits en solutions design urbain pour promouvoir l'idée de mobilité douce. Ainsi, le projet Playful City, porté par la professeure Yvonne N. Delevoye-Turrell du laboratoire SCALab (CNRS, UMR 9193, Université de Lille) s'intéresse à ces interventions sociétales et propose des méthodologies de recherche pour démontrer l'impact du design urbain sur la mobilité spontanée et le bien-être des citoyens.

Classiquement, la recherche académique mène des travaux dans des environnements contrôlés et stériles, c'est-à-dire en laboratoire. Mais cette approche présente des limites importantes. La science d'aujourd'hui ne sait pas vraiment si les résultats obtenus en laboratoire seront confirmés dans des environnements réels.

Grâce aux villes intelligentes et aux objets connectés, il est possible de mesurer le comportement humain en temps réel dans de vrais environnements. Mon travail de recherche est le point de départ de ce laboratoire ouvert sur la ville, incorporant des outils neuroscientifiques pour tester l'impact de différents scénarios de design urbain sur le bien-être perçu et réel des citoyens.

9.3 CO-CRÉATION AVEC LES UTILISATEURS

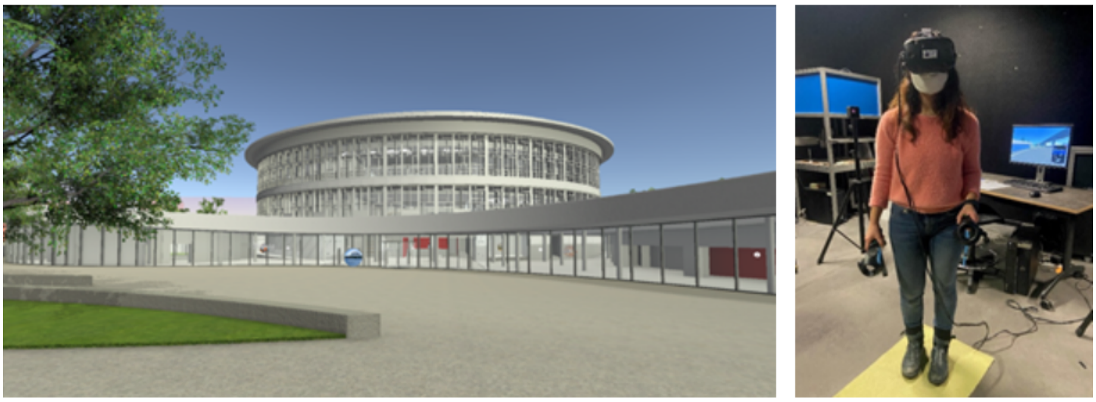
La première phase a consisté à organiser des ateliers avec les utilisateurs pour imaginer des sentiers pédestres ludiques donnant envie de se promener à travers le campus universitaire de Cité Scientifique (Villeneuve d'Ascq). La co-création est un processus collaboratif actif, créatif et social entre producteurs et utilisateurs visant à créer ou améliorer un produit ou un service. La méthode de co-design facilite la génération d'idées avec une perspective plus globale d'un problème et libérant l'émergence de solutions multiples. Ainsi, nous avons appliqué le principe de collaboration active voir figure 70 afin de trouver une réponse au problème d'inactivité caractérisant la population étudiante.

Figure 70: Collaboration active pour récolter auprès des étudiants leur routine de marche spontanée.

Plusieurs ateliers ont été organisés en 2019 pour échanger avec les étudiants, le personnel et les décideurs politiques de l'Université de Lille. L'objectif de cette phase était de comprendre les besoins et les freins des utilisateurs, et de concevoir des prototypes cohérents avec le projet de Campus 2022. Plusieurs parcours colorés, de 30 minutes de marche, ont ainsi été créés afin d'amener la population universitaire à découvrir les espaces moins fréquentés du campus, comme les installations sportives, les espaces verts et les jardins.

9.4 TESTS DES DESIGNS EN RÉALITÉ VIRTUELLE

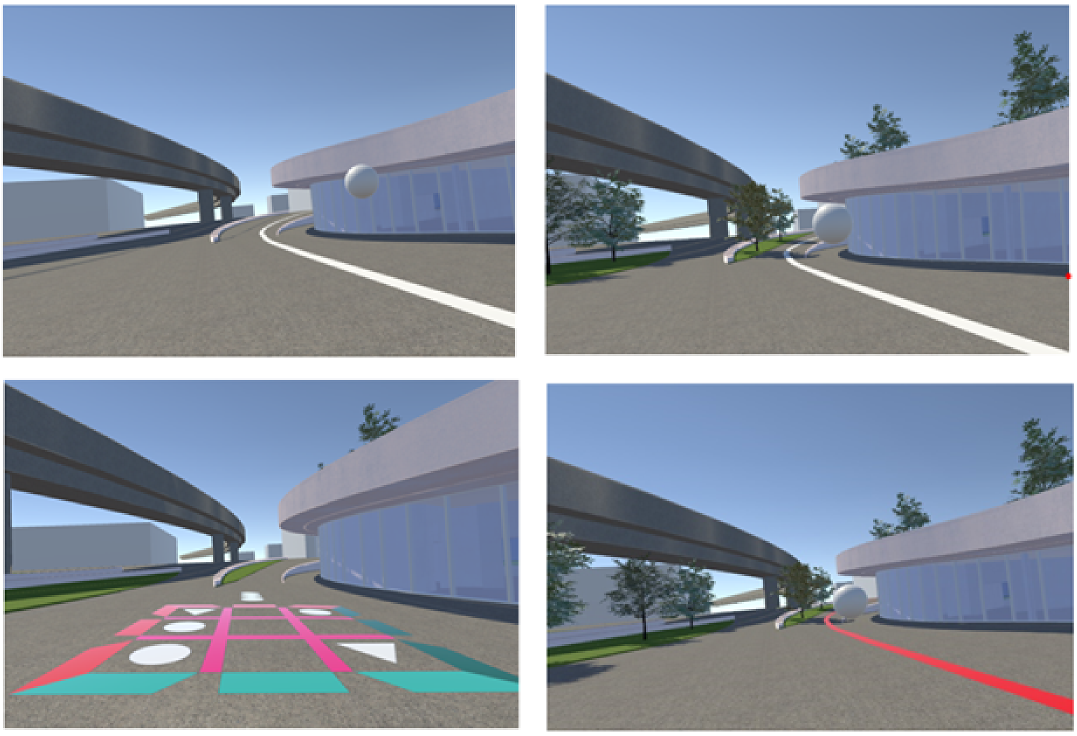
Figure 71: Découverte en réalité virtuelle du bâtiment de Lilliad Learning Center Innovation, Université de Lille, campus Cité Scientifique.



La deuxième phase du projet a consisté à tester ces parcours dans un environnement virtuel immersif. Les parcours étaient complétés par différents scénarios designs en se focalisant autour du bâtiment emblématique de Lilliad voir figure 71, avec la participation de la startup Vertical. La mesure de l'impact de ces designs sur l'utilisateur a été réalisée grâce à l'accompagnement technique des ingénieurs de la plateforme IrDive (Equipex 2011).

Ces évaluations comportementales ont permis de caractériser l'impact de différents environnements colorés voir figure 72 sur les stratégies d'explorations visuelles, de fréquence de marche spontanée mais également d'état psychologique et émotionnel des participants (article soumis pour publication dans Frontiers in Psychology).

Figure 72: Exemples des designs colorés utilisés dans l'étude expérimentale menée en réalité virtuelle, contrastant les effets de la présence ou pas de nature (haut) et des caractéristiques des designs colorés (bas)



Ces paramètres nous ont permis de sélectionner les designs les plus adéquats à implémenter en milieu réel en considérant les contraintes et les particularités de l'environnement urbain offert par le Campus Cité Scientifique.

La réalité virtuelle est un environnement artificiel qui imite le réel autant que possible. Elle permet d'évaluer les ressentis et de mesurer les comportements d'une personne dans un environnement 3D, tout en contrôlant la nature des éléments présentés. Cet outils, baptisé Playful-City VR, est maintenant disponible pour les designers urbains afin de co-créer des environnements centrés sur l'humain, en minimisant les risques (de calendrier, financiers et sanitaires).

9.5 TRANSFERT EN MILIEU NATUREL

La troisième phase du projet a été menée en milieu naturel. À partir des résultats obtenus en réalité virtuelle, les designs ayant eu un impact positif sur les préférences de l'utilisateur, sur la cadence de marche, sur le bien-être ressenti et sur la facilitation à s'orienter ont été sélectionnés pour être implémentés sur le campus.

Figure 73: La ligne verte est dotée de motifs simples et entrelacés pour ralentir la cadence et découvrir les espaces verts (gauche) ; la ligne bleue inclue des blocs colorés et des patterns ludiques (droite) pour entraîner les utilisateurs vers les bâtiments d'enseignements et les lieux culturels de l'Université.

Deux parcours colorés et ludiques ont été réalisés en collaboration avec le département de SUAPS de l'Université de Lille (M.Garcin), le Studio Lebleu (Paris) et la Condition Publique (Roubaix). Chaque parcours était dimensionné pour offrir 30 minutes de marche. Ils incorporaient des scénarios contrastés sur le plan des couleurs, des formes ludiques mais également des points d'intérêts visités voir figure 73.

Une ligne verte aux motifs simples et entrelacés conduit les utilisateurs à travers les espaces verts, les jardins associatifs et également, les installations sportives voir figure 74. Une ligne bleue accompagne les utilisateurs vers les bâtiments d'enseignements et les lieux culturels de l'Université.

Aucune explication n'était donnée aux utilisateurs. Ces designs sont apparus un beau matin de juin 2019 pour colorer les lieux. Des compteurs piétons automatiques ont été mis en place en amont aux points clés du parcours. Ainsi nous avons pu quantifier que les designs ont eu un impact significatif sur le flux piétonnier, avec une augmentation de fréquentations des lieux délaissés.

Figure 74: Des lignes de couleurs contrastées pour inviter les étudiants à découvrir le plaisir de marcher

9.6 MESURES SCIENTIFIQUES EN MILIEU NATUREL

Afin de confirmer l'impact des différents scénarios de design urbain sur le bien-être perçu et réel des étudiants, une étude contrôlée a été menée. Cette recherche a été déclarée au Comité d'Éthique de la Recherche (CER) de l'Université de Lille (référence : 2019-328-S68) et a impliqué la participation de 28 adultes ayant donné leur consentement éclairé avant inclusion.

Nous avons posé les hypothèses selon lesquelles les scénarios designs permettraient (1) de faciliter et d'augmenter l'agréabilité de la marche spontanée sur le campus ; (2) que la découverte des espaces verts de l'Université (ligne verte) aurait des effets bénéfiques sur l'état de bien-être réel et perçu des participants.

Pour répondre à ces questions, le bracelet intelligent AffectTAG a été remis aux participants (collaboration avec la startup Neotrope). Nous avons ainsi pu mesurer la fréquence et variabilité cardiaque, la densité et la puissance émotionnelle ; Des questionnaires sur tablette ont permis de collecter les niveaux perçus de plaisir et de bien-être. Les participants ont été invités à passer l'expérience deux fois : une fois avant et une fois après l'implémentation des designs colorés par la Condition Publique.

9.7 Constatations notables

Mener des études scientifiques en milieu naturel n'est pas chose facile puisqu'il faut s'adapter aux aléas météorologiques. Cependant, les résultats sont notables. En effet, des changements de cadence de marche, de plaisir et de ressentis de bien-être ont été observés notamment dans la zone verte du campus (espaces ouverts des terrains de football ; forêt et jardins du campus).

Nos mesures confirment, globalement, que la nature peut déclencher des expériences affectives positives. Les couleurs offrent la perception d'un environnement plus sécure et propre. Des interventions ludiques peuvent transformer la marche en une expérience plus agréable. C'est ainsi que nous avons mis en évidence des différences significatives dans les niveaux de valence perçue (un indicateur de plaisir) pour l'environnement transformé. Le marquage au sol facilite la navigation dans des zones inconnues et encourage à s'y engager. Les indicateurs objectifs ont confirmé que les interventions ont diminué de manière significative la charge cognitive (un indicateur d'effort) pour traverser les routes et prendre des décisions aux croisements de carrefours.

9.8 Leçons pour l'aménagement urbain

Mes travaux de recherche ont mis en lumière l'importance de la trans-disciplinarité. Les principes de co-conception associés à l'innovation – réalité virtuelle et bracelets connectés - ont permis de créer une méthodologie puissante, permettant de prototyper des designs urbains centrés sur l'humain. Nous rapportons un Proof Of Concept (POC) démontrant que les outils de recherche peuvent être transférés et utilisés à l'extérieur des murs du laboratoire pour tester et mesurer ce qui fonctionne et ce qui ne fonctionne pas en design. Les interventions temporaires sont des approches peu coûteuses qui sont faciles à mettre en œuvre ; elles peuvent donner des indications précieuses sur les éléments de conception urbaine qui peuvent influencer le comportement spontané d'une personne.

Les méthodes de recherche doivent à l'avenir être pris en compte dans les politiques de la ville. En effet, l'architecture de la ville urbaine impacte la qualité de vie de la population. Les villes devraient donc envisager de soutenir la création de prototypes, mais aussi mesurer et tester les solutions de design avant de les rendre permanentes.

Notre projet permettrait de prioriser la transformation de l'espace public pour promouvoir le bien-être et l'activité physique de leurs citoyens. Grâce à des transformations sensorielles, de part une intervention colorée et ludique, il serait possible d'orienter les citoyens vers les lieux délaissés comme les aires de jeux, les gymnases, les parcs et les centres culturels. Un parcours citoyen pourrait même être imaginé pour favoriser la visite de magasins locaux pour soutenir les producteurs locaux.

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