Université de Lille
Ecole Doctorale Sciences de l'Homme et de la Société
Faculté PsySEF–Psychologie et Sciences de l'Éducation et de la Formation
SCALab - UMR CNRS 9193

# PERIPERSONAL SPACE REPRESENTATION AND EXPLOITATION IN RELATION TO MOTOR AND SOCIAL FACTORS: TOWARDS A FUNCTIONAL CONSTRUCTION OF THE SPACE AROUND THE BODY

*Représentation et exploitation de l'espace péripersonnel en fonction des facteurs moteurs et sociaux: Vers une construction fonctionnelle de l'espace autour du corps*

*Thesis submitted and defended*
*by*
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*Supervised*
*by*
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Maria Francesca Gigliotti

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*Peripersonal space representation and exploitation in relation to motor and social factors: Towards a functional construction of the space around the body*

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*Na vota, cc'eranu due chi avìanu nu saccu de lenticchie de cuntàre.*
*Unu si disperava e chiangìa :*
*≪Mamma, ca cumu am'e fhare? 'Un finimme cchiù! Cumu nde nescìmu? ≫*
*L'atru cce disse:*
*≪Vue sapire cumu?*
*Tuni ncigna a cuntàre. Ca pue se vide.≫*

— A Chicchina.

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# ACRONYMS

| | |
|---|---|
| ACC | anterior cingulate cortex |
| aIPS | anterior intra-parietal sulcus |
| ASD | autism spectrum disorder |
| dPOS | dorsal parieto-occipital sulcus |
| EEG | electroencephalography |
| EMMs | estimated marginal means |
| IPS | intra-parietal sulcus |
| MAD | median absolute deviation |
| MEPs | motor evoked potentials |
| M1 | primary motor cortex |
| OMMs | ordinary marginal means |
| PPC | posterior parietal cortex |
| PPS | peri-personal space |
| SPOC | superior parieto-occipital cortex |
| STS | superior temporal sulcus |
| TD | typically developing |
| TMS | transcranial magnetic stimulation |
| VIP | ventral intra-parietal area |
| vPMC | ventral pre-motor cortex |

# ABSTRACT

The peripersonal space (PPS) has been defined as the action space immediately surrounding the body where individuals can easily interact with objects and people. PPS acts as a perception-action interface that allows a multisensory encoding of nearby stimuli and plays a crucial role in the organisation and guiding of goal-directed or defensive actions. PPS would be composed by multiple response-fields. Each response-field consists in a portion of space endowed with a given functional value that determines the most pertinent action to be potentially executed. Within this context, the aim of the present thesis was to assess whether and how social and motor factors are integrated when constructing such functional representation of space. Specifically, I tested the general hypothesis that when motor and social factors are concurrently involved, social factors modulate the influence of motor factors on the construction of PPS. The two facets of PPS construction were examined: PPS *representation* (i.e., the way individual represent their near-body space) and PPS *exploitation* (i.e., the way individuals act within their near-body space). Five studies were conducted in the present thesis. Study 1 showed that during a collaborative motor task with a confederate, individuals extend their PPS representation. However, they tend to avoid exploiting space when this coincides with the confederate's PPS, even when associated to a higher possibility to obtain a reward following a motor action. Study 2 showed that this effect is modulated by individuals' motor involvement in the task (i.e., acting vs. observing). Study 3, 4 and 5 focused specifically on PPS exploitation and showed respectively that the use of space during social interaction is modulated by the features of the final spatial target of the motor action, the availability of gaze and the sharing of a physical space. Therefore, while Study 1 and 2 showed that social factors modulate the effect of motor factors, Study 3, 4 and 5 suggested that the reverse effect is also possible. These findings suggest that social and motor factors are hierarchically taken into account when representing and exploiting peri-personal space (PPS), determining whether and how they prioritise a given portion of space during their interactions with the environment. In light of the present findings and in order to offer an integrative view of PPS construction, the present thesis proposes a functional model of PPS, including three interconnected and mutually influencing layers (a perceptual priority map, a motor priority map and an action execution stage). From a wider perspective, the present thesis defends the idea that PPS construction is not stable, but computed in a specific instant as a function of the task demands, stimuli features and the physical and social context.

*Keywords:* Peripersonal space, Action, Social intention, Reward prospects, Interaction

# RÉSUMÉ

L'espace péripersonnel (PPS) a été défini comme l'espace d'action entourant le corps où les individus peuvent facilement interagir avec les objets et les individus. Le PPS agit comme une interface entre perception et action qui permet un encodage multisensoriel des stimuli à proximité et joue un rôle crucial dans l'organisation et l'exécution d'actions visant la protection du corps ou l'interaction avec des objets. Le PPS serait composé de plusieurs champs de réponse, à savoir des portions d'espace dotées d'une valeur fonctionnelle déterminant l'action la plus pertinente à exécuter. Dans ce contexte, l'objectif de la présente thèse était d'évaluer si et comment les facteurs sociaux et moteurs sont intégrés lors de la construction d'une telle représentation fonctionnelle de l'espace. Plus précisément, j'ai testé l'hypothèse selon laquelle, lorsque des facteurs moteurs et sociaux sont simultanément impliqués, les facteurs sociaux moduleraient l'influence des facteurs moteurs sur la construction du PPS. Les deux facettes de la construction des PPS ont été examinées : la *représentation* du PPS (i.e., la façon dont les individus se représentent l' espace autour de leur corps) et l'exploitation du PPS (i.e., la façon dont les individus agissent dans cet espace). Cinq études ont été menées dans le cadre de la présente thèse. L'étude 1 a montré que lors d'une tâche motrice en collaboration avec autrui, les individus étendent leur représentation du PPS. Cependant, ils ont tendance à éviter d'exploiter l'espace lorsque celui-ci coïncide avec le PPS d'autrui, même lorsqu'il est associé à une plus grande probabilité d'obtenir une récompense suite à une action motrice. L'étude 2 a montré que cet effet est modulé par l'implication des individus dans la tâche (i.e., agir vs. observer). Les études 3, 4 et 5 ont examiné spécifiquement l'exploitation du PPS et ont montré respectivement qu'en situation d'interaction sociale, l'utilisation de l'espace est modulée par les caractéristiques de la cible spatiale à atteindre à la fin de l'action, la présence du regard d'autrui et le partage d'un espace physique. Par conséquent, alors que les études 1 et 2 ont montré que les facteurs sociaux modulent l'effet des facteurs moteurs, les études 3, 4 et 5 ont suggéré que l'effet inverse est également possible. Ces résultats suggèrent donc que les facteurs sociaux et moteurs sont pris en compte de façon hierarchique lorsque les individus se représentent et exploitent leur PPS, attribuant une priorité donnée à une portion d'espace donnée durant leurs interactions avec l'environnement. A la lumière de ces résultats et afin d'offrir une vision intégrative de la construction du PPS, la présente thèse propose un modèle fonctionnel du PPS, comprenant trois niveaux inter-connectés et s'influençant mutuellement (une carte des priorités perceptives, une carte des priorités motrices et une étape d'exécution de l'action). Dans une perspective plus large, la présente thèse défend l'idée que la construction du PPS n'est pas stable, mais qu'elle est déterminée à un instant précis par les exigences de la tâche, les caractéristiques des stimuli et le contexte physique et social.

*Mots-Clés:* Espace péripersonnel, Action, Intention sociale, Perspectives de récompense, Interaction

# PUBLICATIONS

## ARTICLES IN REFERRED JOURNALS

- **Gigliotti, M.F.**, Sampaio, A., Bartolo, A., Coello, Y. (2020). The combined effects of motor and social goals on the kinematics of object-directed motor action. *Scientific Reports*, 10(1), 1-10. https://doi.org/10.1038/s41598-020-63314-y
- **Gigliotti, M.F.**, Soares Coelho, P., Coutinho, J., & Coello, Y. (Published in 2019, Issue Date 2021). Peripersonal space in social context is modulated by action reward, but differently in males and females. *Psychological Research*, 85, 181–194. https://doi.org/10.1007/s00426-019-01242-x
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## ARTICLES UNDER REVIEW IN REFERRED JOURNALS

- **Gigliotti, M.F.**, Bartolo, A., Coello, Y. (*sumbitted*). Paying attention to the outcome of others' actions has dissociated effects on observer's peripersonal space representation and exploitation.

## ARTICLES IN PREPARATION

- **Gigliotti, M.F.**, Ott, L., Bartolo, A., Coello, Y. (*in prep.*). The contribution of eye gaze and movement kinematics to the expression and the identification of social intention in object-directed motor actions.
- **Gigliotti, M.F.**, Bartolo, A., & Coello, Y. (*in prep.*). "Screens make us less social": The effect of social intention on action kinematics is intrinsically related to the sharing of a same physical space.
- **Gigliotti, M.F.**, Desrosiers, P.A., Ott, L., Daoudi, M., Bartolo, A., & Coello, Y. (*in prep.*). Do we behave in front of a virtual agent as we would do in front of a real human being?: A kinematic study of the effect of social intention on action execution.

- **Gigliotti, M.F.**, Ott, L., Bartolo, A., & Coello, Y. (2022, August). *The contribution of eye gaze and movement kinematics to the expression and the identification of social intention in object-directed motor actions.*

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- Baillard, A. & **Gigliotti, M.F.** (2018, October). *Diagnostic et prise en charge de la cécité corticale : illustration de stratégies de rééducation inspirées des méthodes et des données de la recherche élaborées spécifiquement pour les cas des patients BE et LJ.*

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- **Gigliotti, M.F.**, & Coello, Y. (2018, September). *Perceiving and acting in a common and shared space: a systematic exploration of the social dimension of peri-personal space.*

  [Poster Session]. ICSC - International Conference of Spatial Cognition, Rome, Italy.

- Coello, Y., **Gigliotti, M.F.**, Coelho, P., & Quesque, F. (2018, September). *The social dimension of peripersonal space.*

  [Conference Session]. ICSC - International Conference of Spatial Cognition, Rome, Italy.

- **Gigliotti, M.F.**, Quesque, F., Ott, L., Bruyelle, J.L., & Coello, Y. (2017, December). *Influence de nos actions dans l'environnement et du contexte social sur la perception de l'espace péri-personnel.*

  [Conference Session]. XIIe Journée Scientifique des Jeunes Chercheurs en Psychologie, Lille, France.

- **Gigliotti, M.F.**, Quesque, F., Shemakova, E., & Coello, Y. (2017, october). *Effect of the positive-negative consequences of motor actions and the social context on the representation of peripersonal space.*

  [Poster Session]. GDR Vision, Lille, France.

- Coello Y., Quesque F., **Gigliotti, M.F.**, Shemakova E., Ott L., & Bruyelle J-L. (2017, August). *Consequences of motor actions and social context determine the representation of peripersonal space.*

  [Poster Session]. ECVP - European Conference on Visual Perception, Berlin, Germany.

- Coello, Y., Quesque, F., **Gigliotti, M.F.**, & Shemakova, E. (2017, September). *Effect of the positive-negative consequences of motor actions and the social context on the representation of peripersonal space.*

  [Conference Session]. ESCOP - Conference of the European Society for COgnitive Psychology, Potsdam, Germany.

### WORKSHOPS

- **Gigliotti, M.F.** (2019, November). *Representation and exploration of peripersonal space as a function of action's reward and social context.*

  Talk given at the workshop *Cross-Border Vision of the Links Between Action and Cognition in Psychology* organised by Michael Andres (Catholic University of Louvain-La-Neuve) and Solène Kalénine (University of Lille). Louvain-La-Neuve, Belgium.

- **Gigliotti, M.F.**, Sampaio, A., Bartolo, A., & Coello, Y. *The neural basis of Motor and Social Intention perception: an IRMf study.*

  Research project in collaboration with the Psychological Neuroscience Lab, Research Center in Psychology (CIPsi) of the University of Minho, Braga, Portugal.

- Gaggero, G., Brunellière, A., **Gigliotti, M.F.**, El mardi, W., Fasquel,A., Bakkali, N., Doba, K., Nandrino,J-L., Coello, Y., Berthoz, S., & Grynberg, D. (*pre-registered*) *Comparing the psychometric properties between three French translations of the Interpersonal Reactivity Index (IRI).*

  Research project conducted in collaboration with members of the research teams DEEP (Dynamique Emotionnelle Et Pathologies) and LANGAGE of the laboratory SCALab (UMR CNRS 9193) of the University of Lille, France.

- Noury, A., **Gigliotti, M.F.**, & Louis, A. *The relationship between fictional narratives and their audience: a field study on Tolkien's and Dumas' narratives appropriation.*

  Research project in collaboration with the Centre de Recherches sur les Arts et le Langage (CRAL - UMR 8566 EHESS/CNRS), at the EHESS - École des Hautes Etudes en Sciences Sociales, Paris, France.

- Noury, A. & **Gigliotti, M.F.** (2022, February) *The relationship between fictional narratives and their audience: a field study on Tolkien's and Dumas' narratives appropriation.*

  Seminar session at the Centre de Recherches sur les Arts et le Langage (CRAL - UMR 8566 EHESS/CNRS). EHESS - École des Hautes Etudes en Sciences Sociales, Paris, France.

# TEACHINGS

## classes given from 2018 to 2022, for a total of 266 hours

| | | | |
|---|---|---|---|
| Master, 2nd year | Psychology | 2hCM, 1hTD | *Introduction to kinematic analysis (Master PPNSA[a]).* |
| Master, 2nd year | Psychology | 3hCM, 3hTD | *Sensory substitution and human enhancement (Master PPNSA).* |
| Master, 1st year | Psychology | 8hTD | *Cognitive Psychology, Neurocognition and pathology (Master PPNSA).* |
| Bachelor, 3rd year | Psychology | 8hTD | *Motor Control (Cognitive Psychology).* |
| Bachelor, 3rd year | Psychology | 6hCM | *Action and Vision (Cognitive Psychology).* |
| Bachelor, 3rd year | Psychology | 8hCM, 8hTD | *Attention: definitions, theoretical models and applications (Cognitive Psychology).* |
| Bachelor, 3rd year | Psychology | 4hTD | *Student's project: research and internship seminar.* |
| Bachelor, 3rd year | Psychology | 4hCM | *Children's Development within a Digital Environment (Experimental Psychology applications for business innovation).* |
| Bachelor, 3rd year | Psychology | 4hCM | *Sensations, Perceptions and Virtual Spaces (Experimental Psychology applications for business innovation).* |
| Bachelor, 3rd year | Psychology | 4hCM | *The role of Cognitive Psychology in UX Design (UX Design and Sensorial Marketing).* |
| Bachelor, 3rd year | Psychology | 4hTD | *The variables inducing the feeling of immersion: analysis of the introduction of the video-game "Hellblade: Senua's Sacrifice" (UX Design and Sensorial Marketing). In collaboration with Aurore Noury, PhD Student at the CRAL- UMR CNRS 8566, EHESS.* |
| Bachelor, 1st year | Psychology | 36hTD | *Developmental Psychology.* |
| Bachelor, 1st year | Psychology | 18hTD | *Cognitive Psychology.* |
| Bachelor, 1st year | Psychology | 96hTD | *Disciplinary Methodology.* |
| Bachelor, 1st year | Psychology | 36hTD | *Satistics applied to Psychology.* |
| Bachelor, 1st year | MIASHS[b] | 4hCM, 3hTD | *Sensory substitution and human enhancement.* |
| Bachelor, 1st year | MIASHS | 6hTD | *Perception and motricity.* |

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[a] PPNSA: Psychologie des Processus Neurocognitifs et Sciences Affectives

[b] MIASHS: Mathématiques et Informatique Appliquées aux Sciences Humaines et Sociales

# Part I

# THEORETICAL FRAMEWORK

# 1

# THE SPACE AROUND THE BODY

## 1.1 A FRAGMENTED REPRESENTATION OF SPACE

Interacting with the surrounding environment is a complex process, which relies on a series of computations performed by the brain. Such computations aim at identifying the nature of the ambient stimuli, localizing them with respect to the body, and determining the current state of the body-parts in order to prepare the appropriate motor response and properly interact with a given stimulus. Among that series of computations, the distinction between closeness and distance plays a central role. Indeed, although the environment in which we are embedded is visually and auditory perceived as being homogeneous and continuous, this is not the case at the cognitive and neuronal level.

Over the last two decades, numerous neurophysiological, neuroimaging and behavioural studies have identified and described distinct cerebral networks specialised in the coding of stimuli depending on their distance in space from the body (for a review, see Cléry et al., 2015; Serino, 2019). One of the early evidence of a dissociation between the processing of far and near space was provided by Brain (1941) during a multiple-case study of brain-injured patients. The author observed that some patients presented deficits in localizing, pointing to and grasping objects within hand reach when located in the hemi-space opposite to the damaged brain hemisphere. Some patients displayed the opposite pattern, with difficulties in localizing objects when placed at a greater distance from the body but no deficits in processing objects when located within a reachable distance. Such selective impairment of stimuli processing depending on their location in space led the authors to conclude on the existence of a dissociation between a “grasping distance” and a “walking distance”, which was later confirmed by behavioural, neuropsychological and neuroimaging studies conducted in primates (e.g., Rizzolatti et al., 1983; Rizzolatti et al., 1981) and humans (e.g., Halligan et al., 2003; Ortigue et al., 2006).

On the basis of these findings, several models have been proposed to describe and define the segmented representation of space (e.g., Cardinali et al., 2009a; Cléry et al., 2015; Goodale & Milner, 1992; Previc, 1998; Rizzolatti et al., 1981). Beyond some slight differences among the proposed conceptions, there is common agreement to distinguish at least three sub-spaces (Cardinali et al., 2009a; Cléry et al., 2015; Serino, 2019): (a) the *personal space*, corresponding to the space occupied by the body, which is coded in proprioceptive, interoceptive and tactile terms; (b) the space immediately surrounding it (named *peri-personal space*), which is coded in tactile, proprioceptive auditory and visual terms and that is directly implicated in the interaction with objects and people; and finally, (c) the space far from the body (named *extra-personal space*), coded in visual and auditory terms, which does not allows direct motor interactions but subserves locomotion, orientation and visual search (Cardinali et al., 2009a; Craig, 2003; Previc, 1998; Rizzolatti et al., 1981).

In the context of the present research work I will only focus on the notion of PPS as it is the portion of space where individuals interact with objects and people (Coello & Cartaud, 2021; de Vignemont & Iannetti, 2015; di Pellegrino & Làdavas, 2015). The representation of such space results from the integration of multiple information stemming from the visual, auditory, tactile, vestibular, proprioceptive and somatosensory systems (Makin et al., 2007; Previc, 1998; Van Der Stoep et al., 2015; Van Der Stoep et al., 2016). Moreover, such representation would be composed of multiple fields, each one associated with a specific value and relevance for the execution of defensive or purposeful actions (Bufacchi & Iannetti, 2018). Because of its relevance for the interaction with the environment, PPS representation is characterised by a high degree of plasticity and a sensitivity to the effect of several factors. In the following sections we will describe the brain correlates of PPS representation, illustrate the factors modulating it and outline its principal function.

## 1.2 NEUROPHYSIOLOGICAL ORIGINS OF THE PERIPERSONAL SPACE NOTION

The term *peripersonal space* was first introduced by Rizzolatti et al. (1981) to define a specific population of neurons identified in the macaques' peri-arcuate cortex during a single-cell electrophysiological study. The population identified by the authors implied a group of bimodal neurons (i.e., neurons exhibiting suprathreshold responses for stimuli stemming from more than one sensory modality) that fired when a tactile and a visual stimuli were concurrently presented in the space in proximity to the animal's body or directly on its skin. Two classes of such bimodal neurons were observed: the *peri-cutaneous neurons*, which discharged for visual and tactile stimuli occurring simultaneously few centimetres from the skin, and the *distant peri-personal neurons*, whose activation was registered for bimodal stimuli presented under approximately 30 centimeters from the macaque's hand, arm or head.

Following in the footsteps of Rizzolatti and colleagues' works, further researches identified additional populations of visuo-tactile neurons in other brain regions (see Section 2.1; Avillac et al., 2007; Duhamel et al., 1998; Leinonen et al., 1979; Leinonen, 1980), as well as other class of bimodal neurons responding to the concurrent presentation of a tactile and an auditory stimulus (Graziano et al., 1999). Some other studies discovered also the existence of trimodal, visuo-audio-tactile neurons (Graziano & Gandhi, 2000; Graziano et al., 1999), which showed a sensitivity to the concomitant presentation of stimuli stemming from three sensory modalities (i.e., visual, tactile and auditory).

The capability of these neurons to integrate multisensory inputs derives from their physiological structure: the presence of multiple receptive fields.

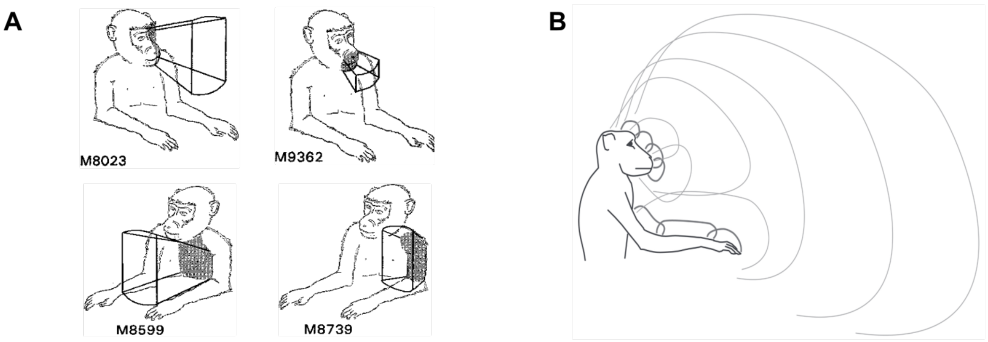
## 1.3 THE PHYSIOLOGICAL AND STRUCTURAL FEATURES OF PERIPERSONAL NEURONS

The mean feature of multisensory neurons are their overlapping double or triple receptive fields: They are endowed with a tactile receptive field, which covers the skin of a body part, and with a visual or/and an auditory receptive field, which extends to and encloses the space around this same body part (see Figure 1.1A). Due to the spatial overlap between the tactile and the visual (or auditory) receptive fields, PPS-related bimodal neurons are able to synthesise inputs stemming from different sensory modalities, on the condition that they are presented synchronously and in a congruent spatial location (Avillac et al., 2005). Although there are very few studies showing that PPS neurons perform actively multisensory integration (Avillac et al., 2007), it has been observed that PPS coding often coincides with multisensory integration processes (Bernasconi et al., 2018; Cléry & Ben Hamed, 2018).

One of the peculiarities of the multiple receptive fields of PPS neurons is that their size is highly variable according to the body part they cover (see Figure 1.1B). For some visuo-tactile neurons, the tactile receptive field covers the face or the hand, while the visual receptive field encompasses a tiny portion of space around it less than 10 cm (e.g., Gentilucci et al., 1988; Rizzolatti et al., 1981). For some others, the double receptive field covers the whole arm and the space 10–60 cm around it (Bremmer et al., 2001; Fogassi et al., 1992; Graziano & Gandhi, 2000; Graziano & Cooke, 2006; Graziano et al., 1997; Rizzolatti et al., 1981). For even others, the visuo-tactile field covers the trunk surface and extends to the space within reach (Fogassi et al., 1996); some others cover one side of the body or even the whole body (Leinonen et al., 1979), thereby extending out beyond reaching distance. Overall, for 95% of neurons, the multisensory integration mechanism applies to the space within reach. For the remaining 5%, such mechanism covers also the space few meters distant from the body (Graziano, 2018). In light of theses observations, Graziano (2018) suggested that PPS mechanisms would not be *limited to* the space near the body. Rather, PPS mechanism "greatly *empathizes* the space near the body, but processes distant space as well" (Graziano, 2018, p. 50).

Another peculiarity of the PPS neurons' receptive fields is that they are anchored to the body part they cover (Graziano et al., 1994). Indeed, research has shown that if the body-part is displaced in space, the overlapping receptive field shifts and follows the body part (Fogassi et al., 1996; Graziano et al., 1997). A similar multisensory processing of bi-modal stimuli occurring in the vicinity of a specific body-part and anchored to it was also observed in humans by behavioural (e.g., Bernasconi et al., 2018; Schicke et al., 2008; Serino et al., 2015; Teneggi et al., 2013; Zanini et al., 2021) and neuropsychological studies (e.g., di Pellegrino et al., 1997; Farne et al., 2005; Làdavas et al., 1998; Scandola et al., 2016; Spence et al., 2001). In light of these findings, it was

**Figure 1.1**
*The Modular Nature of PPS Representation*



*Note.* A. Illustration of the tactile (grey area) and visual (black outlined solids) spatially overlapping receptive fields of bimodal neurons in area F4. Each receptive field codes selectively for a given limb of the monkey's body (inspired from Fogassi et al., 1996). B. Schematic illustration of the overlapping receptive fields of different peripersonal neurons. Some neurons specifically encode the space nearby the body-parts. Some other encompass a wider portion of space within reaching distance or extending beyond it (inspired from Graziano, 2018).

therefore suggested that PPS should not only be considered as a unique representation constructed around the whole body, but also, and rather, as the ensemble of multiple body-part centred representations, such as hand PPS, face PPS, trunk PPS or feet PPS (Serino, 2019).

Multisensory integration is a fundamental process that is primarily involved in the perception of body frontiers and in the feeling of body ownership (Ehrsson, 2012). Multisensory integration contributes to the perceived location of the self in space (Holmes & Spence, 2004; Noel et al., 2015b) and interacts with the construction of the body schema (i.e., the multisensory representation of body structure and its parts' metrics and position in relation to the body; Cardinali et al., 2009a; Maravita et al., 2003). In fact, PPS and body schema representations have been found to share some common brain correlates, such as the anterior intra-parietal sulcus (aIPS), that is mainly responsible for the integration of proprioceptive and tactile information (Makin et al., 2007). Interestingly, the disruption of the integration of visual, proprioceptive, vestibular and tactile information was found to perturb the distinction between personal and extra-personal space. This perturbation generates the so-called "out of body experiences", a feeling of excorporation frequently reported by healthy individuals but also by schizophrenic patients (Blanke et al., 2004).

Apart from contributing to the perception of body integrity, multisensory integration has also been found to serve other functions, such as the perception of stimuli in space in relation to the body. Some authors have proposed that the main role of multisensory neurons would be to situate the stimulus in the space by predicting its impact on the body (Cléry & Ben Hamed, 2018), through the "anticipatory activation" of the overlapping multisensory receptive fields (Hyvärinen & Poranen, 1974). This principle is at the core of studies focusing on looming stimuli, showing that stimuli approaching the body are perceived differently from receding stimuli. In addition, the velocity of the looming stimulus was found to induce an expansion of the visual receptive field (Fogassi et al., 1996), allowing an earlier and more efficient detection of the stimulus position and movement in relation to the body (Bremmer et al., 2013; Colby et al., 1993).

The empirical findings reported in the scientific literature showed that PPS representation is a complex, multi-faced construct, that relies on a specific physiological organisation and is underpinned by a specific mechanism (i.e., the multisensory integration of static and dynamic stimuli occurring in the near-body space). Nevertheless, what is the exact role of such multisensory processing of information? What is its relevance for the organisation of the individuals' behaviours? The next Chapter will aim at elucidating these questions.

# 2

# A SPACE FOR ACTION

Multisensory integration refers to the phenomenon by which two stimuli presented simultaneously elicit a neuronal activation significantly greater (or smaller) than the activation generated by two stimuli presented individually (Avillac et al., 2007; Stein & Stanford, 2008). Multisensory integration constitutes therefore an enhanced (or a reduced) treatment of stimuli, which applies in the case of PPS neurons to events occurring in the near-body space. As a direct consequence, it has been suggested that multisensory integration specific to PPS neurons would be a crucial mechanism that gives "a greater perceptual salience to visual events occurring in the vicinity of the body" (Brozzoli et al., 2012, p. 450), that can potentially constitute the target of a motor action. In the present Chapter, I will present several neurophysiological, neuroimaging, neuropsychological and behavioural studies conducted in both primates and humans showing that stimuli occurring occurring within PPS benefit from an enhanced treatment. These studies will also evidence the association between PPS processing and the organisation of upcoming motor actions.

## 2.1 A SHARED BRAIN CIRCUITRY

Several studies have observed structural similarities between the brain circuit underlying PPS-coding and the one supporting motor performance. As a matter of fact, research has shown that multisensory neurons, ensuring the perception of stimuli, were localised in high-level associative areas that are part of a fronto-parietal network, which is involved in motor planning and execution. In monkeys' brain, this fronto-parietal network includes: the ventral premotor cortex (vPMC, areas 6 and F4; Fogassi et al., 1992; Fogassi et al., 1996; Graziano et al., 1997; Rizzolatti et al., 1981), the posterior parietal cortex (PPC, areas 7a and 7b; Leinonen et al., 1979), the ventral intraparietal area (VIP; Avillac et al., 2007; Colby et al., 1993; Duhamel et al., 1998), the posterior part of the superior temporal sulcus (STS; Bruce et al., 1981) and the putamen (Graziano & Gross, 1993).

A homologuous network has also been identified in the human brain (Bremmer et al., 2001; Brozzoli et al., 2011; Gentile et al., 2011; Grivaz et al., 2017), with several studies confirming the contribution of the vPMC (Bremmer et al., 2001; Ferri et al., 2015), the PPC (Bernasconi et al., 2018) and the VIP area (Avillac et al., 2005; Guipponi et al., 2013) along with the intraparietal sulcus (IPS; Makin et al., 2007), dorsal parieto-occipital sulcus (dPOS, Quinlan & Culham, 2007), superior parieto-occipital cortex

(SPOC, Gallivan et al., 2009), and cerebellum (Bartolo et al., 2014). As a whole, these findings suggest that the brain correlates of PPS representation overlap with the ones subtending motor preparation.

## 2.2 PPS REPRESENTATION SUBSERVES ACTION PREPARATION

### 2.2.1 *The multisensory integration induces motor response facilitation*

The interrelation between PPS representation integration and motor preparation was further evidenced by human behavioural studies exploiting the multisensory integration task. The multisensory integration task consists in detecting the presence of a tactile stimulation while a visual (e.g., a luminous source; Serino et al., 2011) or an auditory stimulation (a sound; e.g., Canzoneri et al., 2012) is delivered synchronously or asynchronously either in the near-body or in the far-from-the body space of participants. The concomitant visual or auditory stimulus can be static (e.g., Serino et al., 2011) or dynamic (e.g., Ferri et al., 2015; Huang et al., 2018), receding from or approaching the participants' body (e.g., Kandula et al., 2015; Serino et al., 2015). The typical pattern of results observed using this task consists in faster reaction times in response to the tactile stimulation when the concomitant visual (or auditory) stimulus is presented synchronously and in the near space. No effect emerges instead when the concomitant stimulus is delivered asynchronously and in the participant's body far space. Such faster motor response is referred to as *cross-modal congruency facilitation*, and is usually explained by a mobilisation of the motor system induced by the multisensory processing of the two stimuli (Finisguerra et al., 2015).

In support of this explanation, Serino et al. (2011) impaired the functional connection between the multisensory integration underlying PPS coding and motor preparation. More precisely, the authors administered to participants a multisensory audio-tactile integration task while temporarily impairing two areas involved in PPS representation (i.e., vPMC and PPC) through transcranial magnetic stimulation (TMS). Interestingly, results showed that the temporary inhibition of these brain areas nullified the cross-modal congruency facilitation induced by the concurrent presentation of the auditory stimulus. This finding serves to confirm that PPS representation and motor preparation are tightly related.

Going one step further, Avenanti et al. (2012) observed analogous results at the electrophysiological level. Using a similar paradigm to Serino et al. (2011), the authors inhibited temporarily the vPMC, implied in PPS representation. Nevertheless, instead of recording participants' reaction times as a proxy of motor preparation processes, they measured the amplitude of motor evoked potentials (MEPs) at the level of the hand through electromyography. Since MEPs at the level of the hand are controlled by the primary motor cortex (M1), the authors were able to test whether altering one of the brain region coding for PPS (i.e, vPMC) the would result in the perturbation of the area involved directly in motor execution (i.e., M1). When no transcranical magnetic stimulation was applied to vPMC, authors observed that the amplitude of MEPs at the level of the hand in response to a tactile stimulation was higher when the concomitant auditory signal was presented in participants' near space than in the far space, confirming the facilitatory role of multisensory integration on motor preparation. On the contrary, following the temporary inhibition of vPMC, the amplitude of MEPs recorded at the level the hand did not differ as a function of the space where the concomitant stimulus was presented during the audio-tactile integration task. As interpretation, the authors considered that the absence of difference in MEPs reflected the alteration of the hand representation excitability in the primary motor cortex. Taken together, these results suggest that altering the functioning of brain areas coding for PPS causes in return a perturbation of motor preparation processes.

### 2.2.2 *Stimuli within PPS are coded in motor terms*

In the previous sections, I have essentially evoked studies focusing on the multisensory mechanism and the processing of stimuli occurring within PPS, which facilitate the activation of motor system. Nevertheless, there exists other evidence of the connection between PPS representation and motor preparation. Such evidence stems from another corpus of studies which has addressed the question of PPS representation from a different point of view. Specifically, in these studies, PPS was not considered as a space where stimuli benefit from a multisensory integration, but rather as the space were stimuli are judged as being at a reachable distance and as potential targets of a motor action[1]. These studies classically measure PPS representation through a more explicit task: the reachability-judgment task (see Coello et al., 2012). The task requires participants to judge whether a stimulus presented at several distances from the trunk can be manually reached by imaging to extend the arm. The maximum distance judged as reachable is referred to as the "reachability threshold", and is considered as the perceived boundary of PPS representation. By means of this task, it was observed that PPS representation depends on an ensemble of parameters related to the agent, such as participants' arm length, the postural stability (Carello et al., 1989) and the degree of freedom of articulations (Rochat & Wraga, 1997), which are at the core of action execution.

In addition, it was also found that objects presented within PPS representation are coded in motor terms, provided that their physical and functional characteristics afford the execution of an action (e.g., Coello et al., 2008; Quinlan & Culham, 2007; Wamain et al., 2016). Accordinlgy, Culham et al. (2008) observed that the presentation of

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[1] A recent study conducted by Zanini et al. (2021) suggested that PPS should not be assimilated to the arm reaching space. Such conclusion was based on the observation that stimuli multisensory integration occurred selectively in the space closely surrounding the hand, while arm reaching space was found to encompass a larger portion of space. However, a recent study conducted in our lab (see Geers et al., in prep) found the opposite result, namely that multisensory integration occurs at a grater distance when compared to the arm reaching limit. Such a divergence might be explained by the body-part used to assess multisensory integration (i.e., the hand in Zanini et al. (2021), and the trunk in Geers et al., in prep.) and indicate that further empirical evidence is needed to clarify the issue of a potential dissociation between PPS and arm reaching space

manipulable objects within participants' near space activated the superior parieto-occipital cortex (SPOC), an area belonging to the dorsal stream of visual system and implicated in reaching acts.

In the same vein, in an electroencephalography (EEG) study, Wamain et al. (2016) observed a significant desynchronization of µ rhythm over the centro-parietal area, a brain oscillation detected during the execution or the observation of an action (Cochin, 1999; Llanos et al., 2013). The µ rhythm desynchronization was observed in the presence of manipulable well-defined objects, but not non-manipulable, scrambled ones, and only when the object was presented in participants' PPS. Moreover, the amplitude of µ rhythm desynchronization decreased progressively from reachable to unreachable stimuli, suggesting a gradual transition from the PPS to extrapersonal space (Bufacchi & Iannetti, 2018).

µ rhythm desynchronization over the centro-parietal region was also found to be stronger when the characteristics of the presented objects relates to the execution of only one type of action, compared to when they evoked multiple potential actions (Kalénine et al., 2016). This perturbation indicate that in PPS, objects are essentially coded in motor terms to prepare the system to the most appropriate action toward the object. Finally, stimulating the left M1 through TMS induced increased MEPs when observing object presented within participants' PPS. Importantly, this effect was observed only when the objects appeared as being manipulable (Cardellicchio et al., 2011). Similarly, the temporary impairment of M1 perturbed also participants' performance at the reachability-judgment task, inducing an increase of reaction times but only when estimating the reachability of stimuli occurring within PPS. Overall, these studies echoes the ones by Serino et al. (2011) and Avenanti et al. (2012), and provide support for the existence of a link between PPS representation and the planning of voluntary motor actions (Coello & Iachini, 2016).

## 2.3 THE OTHER WAY ROUND: ACTION SHAPES PPS REPRESENTATION

The studies presented above showed that PPS representation and the processing of object occurring within it influence motor preparation. In the current section, I will present complementary data approaching the association between PPS coding and motor preparation from the opposite perspective, namely by showing that action planning and execution reshape PPS representation.

### 2.3.1 *The effect of action execution*

The first direct evidence of action planning and execution effects on PPS processing was provided by Brozzoli et al. (2009). The authors assessed participant's detection time of a tactile stimulation delivered on either the index or thumb finger. In the same time, a luminous stimulus was presented on either the top or the bottom parts of a cylinder placed in front of participants, being thereby in a congruent or incongruent spatial position with respect to the tactile stimulation applied to the hand. The novelty of the study was that visuo-tactile integration was assessed either before, at the beginning of or during the execution of a grasping movement towards the cylinder. Results showed that detection times were faster for congruent vs. incongruent visuo-tactile stimulations. Moreover, this cross-modal congruency effect was greater when visuo-tactile stimulation occurred at the beginning of the movement when compared to before and even greater when occurring during action execution. These results were replicated by further studies and showed that multisensory integration is triggered by the action onset and enhanced on-line during the execution of object-directed actions (e.g., Brozzoli et al., 2010; Patané et al., 2019; Senna et al., 2019).

### 2.3.2 *The effect of sensori-motor processing impairment*

Other evidence supporting the effect of motor processing on PPS representation stems from studies altering the sensori-motor system. A reduction of PPS representation was found following damage to the sensory-motor cortex (Bartolo et al., 2014). A similar effect was found after the use of arm splint for 24 hours (Toussaint et al., 2018), which induced motor immobilization and functional temporary impairment of the excitability of the sensorimotor neurons dedicated to limb control (Avanzino et al., 2011; Huber et al., 2006).

On the contrary, an expansion of PPS representation was found following the active use of a tool (e.g., Canzoneri et al., 2013; Holmes, 2012; Witt et al., 2005). Accordingly, it was observed that using a long tool (70 cm), but not a short one (10 cm), induced an increase of the space where multisensory integration occurred (Maravita et al., 2002) as well as an increase of the maximum distance perceived as reachable (Bourgeois et al., 2014). Such extension was explained by an incorporation of the tool to the body schema (Cardinali et al., 2009b; Cardinali et al., 2021; Iriki et al., 1996) leading to a longer arm representation (Miller et al., 2019). Such change in the body schema would result from the alteration of sensori-motor couplings during the active use of the tool (Cardinali et al., 2016). Therefore, due to the functional opportunities offered by the tool, the far space initially perceived as out of reach became perceived as being within reach. Interestingly, although lasting temporarily in healthy individuals, the effect tool use was found to be permanent in blind individuals using regularly a cane (Serino et al., 2011) and in tennis players (Biggio et al., 2017).

As a whole, these findings highlight the implication of sensori-motor processes in PPS representation. More importantly, they also suggest that the integration of current sensori-motor inputs play a crucial role in the perception of *action possibilities* within the PPS.

### 2.3.3 *The effect of action possibilities and action rewards*

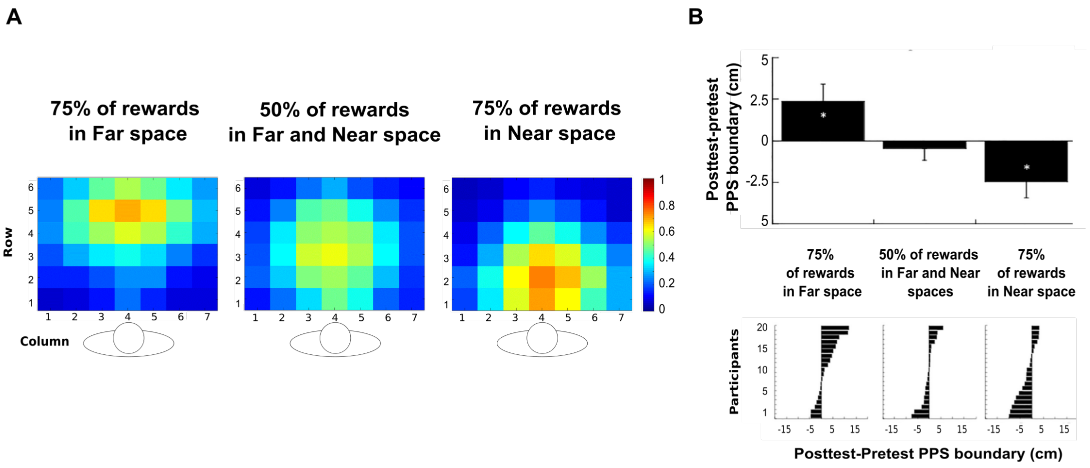
A study conducted by Iachini et al. (2014b) provided evidence for the influence of simulating action possibilities on the construction of PPS representation. In line with the literature, the authors found that participants provided faster and more accurate judgments about objects location when objects were presented in the near, peri-personal space compared to the far, extra-personal space. Nevertheless, this motor facilitation effect observed within PPS was stronger when participants had both arms free to move, but weaker when the dominant hand was blocked behind their back. These results suggest that near-space perception eventually overlaps with the perception of action possibilities towards the objects occurring in this space, through the simulation of an action and its potential consequences.

This anticipatory process would result from previous motor experiences and the integration of feedbacks received from past actions. Corroborating this hypothesis, Bourgeois and Coello (2012) found that altering the sensori-motor anticipatory processes resulted into an alteration of PPS representation. In their study, they provided participants false visual feedbacks about movement end point during a pointing motor task, generating a mismatch between the initial and the actual spatial location targeted by the pointing movement. By providing such false sensori-motor feedbacks, authors induced a visuo-motor re-calibration that was found to impact participants' PPS processing. Specifically, during the first phase of the visuo-motor calibration, PPS was found to constrict, indicating that the perturbation of internal models induced uncertainity that blurred PPS frontiers. During the following phases, PPS representation was found to progressively constrict when the provided sensori-motor feedbacks were shifted towards the participants' body, and to progressively expand when they were shifted away from participant's body. On the basis of such results, we can conclude therefore that near-body space processing is highly dependent on the accuracy of sensori-motor inputs and the effectiveness of internal motor anticipation models.

A last piece of evidence suggesting that PPS representation depends on sensori-motor anticipation and prediction of action outcomes arises from the study of Coello et al. (2018). In their study, the authors assessed PPS representation by means of a reachability-judgment task, performed before and after the execution of a stimuli-selection task on a horizontal touch screen table. The stimuli-selection task consisted in selecting 10 stimuli out of 32 presented on the screen, which, once selected, could either turn to green and yield a reward, or turn to red and yield no reward. According to the condition, the probability to select a reward-yielding stimulus was biased in space, being either 75% in participant's distal or proximal space, or 50% in both spaces. Results revealed that participants selected more stimuli in the space associated with a higher probability to obtain a reward (see Figure 2.1A). Although not noticed, the biased distribution of reward-yielding stimuli in the stimuli-selection task influenced also the performance at the reachability-judgment task. Specifically, PPS boundary was found to (a) extend when reward-yielding stimuli were mainly located in participant's distal

**Figure 2.1**

*Participants' Exploration Strategy and PPS Representation as a Function of Action Rewards Distribution in Space*



*Note.* Reproduced from Coello et al. (2018). A. Participants' performance in the stimuli-selection task. Heat maps illustrate the frequency of choice of a spatial location (red: frequently chosen location; blue: rarely chosen location). Participants tended to explore the area of space associated with the higher proportion of reward-yielding stimuli. B. Participants' performance in the reachability-judgment task. The task was executed before (pretest) and after (posttest) the stimuli-selection task. Histograms represent posttest–pretest group and individual differences in PPS boundary. PPS boundary was found to extend when reward-yielding stimuli were mainly located in participant's distal space, to restrict when located in their proximal space and to remain unchanged when they were randomly distributed in both spaces.

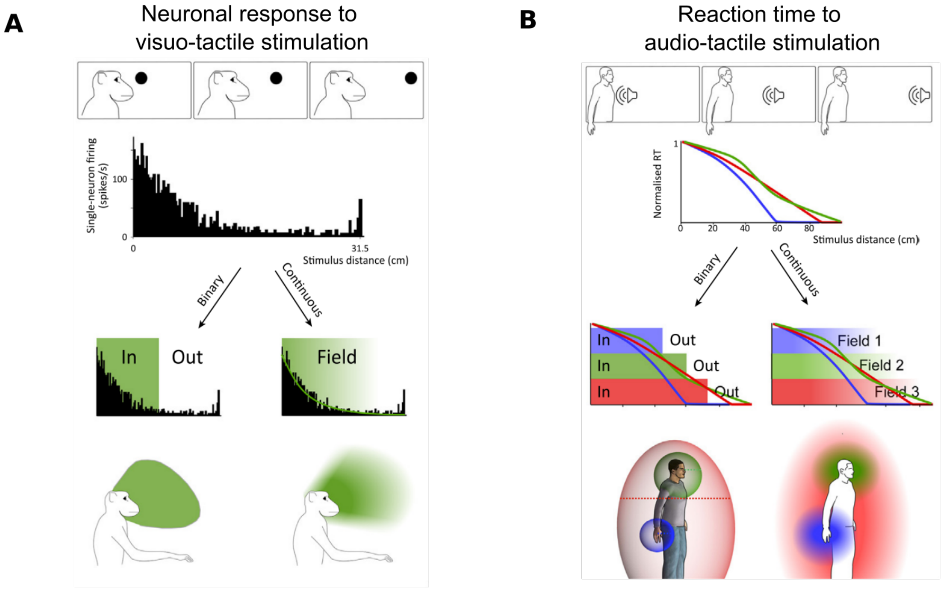
space, (b) restrict when located in their proximal space and (c) remain unchanged when they were randomly distributed in both spaces. These results revealed that the perception of the nearby reachable space depends on objects' value and action rewards prospects, suggesting therefore that PPS representation is constructed as a function of the features of the *hic et nunc* body–objects interactions (Bufacchi & Iannetti, 2018, 2019).

## 2.4 THE FUNCTIONS OF PPS

Since the seminal studies by Rizzolatti et al. (1981), numerous experimental works have investigated the neural and behavioural correlates of PPS perception and explored the factors modulating its representation (for reviews see Cléry & Ben Hamed, 2018; Cléry et al., 2015; Coello & Cartaud, 2021; di Pellegrino & Làdavas, 2015; Hunley & Lourenco, 2018; Makin et al., 2008). Notably, these studies showed that stimuli occurring within PPS undergo a enhanced perceptual and motor treatment; this allows to localize stimuli with respect to the body parts, monitor the direction and speed when stimuli are dynamic, but also fastly evaluate the stimuli features (e.g., identity,

**Figure 2.2**

*In-Out Binary Versus Continuous, Graded Response-Field Representation of PPS*



*Note.* Inspired from Bufacchi and Iannetti (2018). A. In-Out binary versus Continuous, graded response-fields representation of PPS in relation to the response pattern displayed by PPS neurons in monkeys. B. In-Out binary versus Continuous, graded response field representation of PPS in relation to reaction times to multimodal stimulation in humans.

manipulability and value). Considering these findings, it has been suggested that PPS would serve as an highly dynamic and plastic interface between perception and action, subserving two main functions (de Vignemont & Iannetti, 2015; Hunley & Lourenco, 2018).

On the one side, PPS representation would allow the perception of body frontiers and protection of body integrity from approaching hazards (Cléry & Ben Hamed, 2018). In line with this notion, the stimulation of multisensory neurons was found to elicit stereotypical defensive behaviours in monkeys (Iriki et al., 1996). In humans, dangerous stimuli (e.g., spiders or snakes, or sharp tools) were found to be integrated at a greater distance from the body (Vagnoni et al., 2012), but perceived as being nearer when compared to non dangerous stimuli (Coello et al., 2012).

On the other side, PPS representation would play a crucial role in the organisation and guiding of voluntary goal-directed actions towards the objects of the environment. Indeed, PPS representation was found to depend on the features of the objects occurring within this space, and especially on the action possibilities they can afford (e.g., Kalénine et al., 2016; Wamain et al., 2016). Furthermore, PPS representation was found to adjust to the sensori-motor inputs, internal motor anticipation models and reward prospects in space (Bourgeois & Coello, 2012; Coello et al., 2018; Iachini et al., 2014b) as well as during the execution of a motor action and as a function of its final aim (Brozzoli et al., 2010; Brozzoli et al., 2009; Senna et al., 2019).

In light of all the findings presented above, an original and more integrative model has been recently proposed by Bufacchi and Iannetti (2018) to define PPS. In their *Action Field Theory of Peripersonal Space* (Bufacchi & Iannetti, 2018, 2019), the authors highlighted the risk of a biased interpretation of PPS due to the characteristics of the employed measures. As a consequence, they proposed to abandon the vision of PPS a single, binary in-or-out zone based on the near-distant dichotomy. Alternatively, they suggested to consider PPS representation as the resultant of "the integration of a set of graded fields describing behavioural relevance of actions aiming to create or avoid contact between objects and the body" (Bufacchi & Iannetti, 2018, p. 1). According to Bufacchi and Iannetti's theory, PPS representation would be thereby a sum of multiple motor response-fields, characterised by graded instead of clear and sharp margins (which is more in accordance with the continuous and gradual responses observed in PPS neurons, e.g., Fogassi et al., 1996; Graziano et al., 1994, see Figure 2.2). Such fields would be associated with a specific functional value and behavioural relevance. Said differently, each field would be associated with a certain value that will determine the actions to be executed. Such value would not be permanent but rather computed instantaneously as a function of the constraints of the ongoing task and the environmental circumstances, and this for a specific portion of space in a specific time (Bufacchi & Iannetti, 2019). Therefore, such multiple action-field conceptualisation of PPS would allow the selection of the most pertinent action, whether it aims to create or avoid contact with a given stimulus. The vision of Bufacchi and Iannetti (2018) is also in line with the empirical evidence provided by Coello et al. (2018) (see Section 2.3.3), which showed that associating a certain reward to a portion of space modified action selection and concurrently individuals' PPS representation. Such multiple, instantaneously determined response-fields construction of PPS will be at the core of the present thesis.

# 3

# A SPACE FOR SOCIAL INTERACTIONS

In the previous chapter, I described the physiological and sensori-motor mechanisms underlying the perception of the space immediately surrounding the body. I further talked about how, by influencing these mechanisms through various factors, it is possible to induce a modification of PPS boundaries. I concluded stating that PPS can be considered as a perception–action interface allowing the individual to interact with its immediate environment, subserving approach-driven, goal-directed behaviours towards non threatening stimuli as well as avoidance-driven, defensive behaviours against potentially harmful stimuli (Coello et al., 2012; Coello & Cartaud, 2021; de Vignemont & Iannetti, 2015; di Pellegrino & Làdavas, 2015; Graziano & Cooke, 2006; Hunley & Lourenco, 2018).

Nevertheless, during their interactions with the environment, individuals rarely behave as independent agents. Indeed, most of our daily actions occur while other agents are actively or passively present in our environment, and with whom we might engage in interaction to manipulate an object of common interest (e.g., a cup). Two main consequences arise from this consideration. First, the presence of a confederate in the nearby space constitutes a stimulus of the environment that has to be taken into account, as it might represent a potential danger for one's body integrity or an obstacle to action execution. Second, being sensitive to others' presence necessarily implies taking into account their action possibilities, in order to understand what they are doing, why and where they are doing a given action, and what they are going to do next.

## 3.1 PPS AS A SAFETY BUFFER ZONE FOR AVOIDING INVASION

The effect of the presence of a confederate on the space perception has been the object of several studies. Taking root from the notion of proxemics[1], and personal space (Hall, 1966; Sommer, 1959), some of these studies aimed at defining how humans use and organise space during social interactions, focusing notably on how they optimally adjust the distances between them in order to communicate efficacy while avoiding discomfort and space intrusion (Hayduk, 1983; Kennedy et al., 2009; Lloyd, 2009). In that respect, interpersonal distance regulation was found to depend on people characteristics, with preferred distance varying as a function of the confederates' age and gender (Hecht et al., 2019; Iachini et al., 2014a; Iachini et al., 2016; Uzzell & Horne,

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[1] Proxemics refers to the study of space and how individuals uses it during social interactions. The term was coined by the cultural anthropologist Edward Twitchell Hall in 1966 (Hall, 1966)

2006), the positive or negative valence of their emotional facial expressions (Cartaud et al., 2020; Ruggiero et al., 2017) and the aggressive content of a conversation (Vagnoni et al., 2018). Furthermore, the regulation of interpersonal distance was found to rely on higher-order social factors. For instance, greater distances were preferred when facing a confederate described as being immoral (Iachini et al., 2015a; Pellencin et al., 2018). Another example entails social affiliation feeling, with shorter interpersonal distance preferred in front of in-group members compared to out-group members (Fini et al., 2020).

Moving one step further, some other studies have suggested that interpersonal distance regulation might also be rooted in motor representations, being therefore intrinsically related to PPS representation (Coello & Cartaud, 2021). Empirical evidence showed indeed that distance adjustment in social context depends on individuals' height and arm length (Hayduk, 1983; Pazhoohi et al., 2019). Consequently, extending PPS representation through tool use was found to induce an increase of the interpersonal distance judged as comfortable when another individual enters one's PPS (Quesque et al., 2017). Nevertheless, this last result is still controversial as other researches have found no effect of tool use on interpersonal distance (Patané et al., 2017). These diverging results could be explained on the one side by the different nature of the social stimuli employed by the authors (human-like point-light display by Quesque et al. (2017), and real confederate in Patané et al. (2017) and on the other, by the active (i.e., the participant approaches the confederate; Patané et al., 2017) or passive (i.e., the confederate approaches the participant Quesque et al., 2017) attitude adopted during the interpersonal distance task used, which was already observed to modulate interpersonal distance regulation (Iachini et al., 2014a).

More interestingly, human behavioural studies found that the presence of others altered the multisensory integration processes at the basis of PPS representation (Heed et al., 2010), inducing a constriction of the space where stimuli benefitted from multisensory integration (Teneggi et al., 2013). Such effect was found to be specific to human beings, as the presence of a human-like mannequin did not induce any change (Teneggi et al., 2013). Moreover, it was observed that modulating the social context can also lead to an expansion of PPS boundaries, for instance following the execution of a task with a cooperative confederate (Pellencin et al., 2018; Teneggi et al., 2013) or after sharing synchronous somatosensory experiences on the body surface with a confederate (Maister et al., 2015).

Taken as a whole, these findings suggest that in the presence of others, individuals calibrate both their interpersonal distances and action space in order to maintain a certain private safety area. However, these results also suggest that PPS representation can be adjusted according to the characteristics of a given social context, so that to facilitate the interaction. Along with the aforementioned studies, another research branch has approached the impact of social context on PPS representation from a different perspective. These studies posit that space processing is functionally related to the planning and execution of actions performed individually or in collaboration with other individuals. Therefore, two factors play a key role in this context: being sensitive to the events occurring in others' PPS and anticipating others' action possibilities within that space. These issues will be the topic of the next section.

## 3.2 DETECTING EVENTS OCCURRING IN OTHERS' PPS

The capability to be sensitive to events occurring in others' PPS has been observed by several neurophysiological and neuroimaging studies. Accordingly, Ishida et al. (2010) identified a group of bimodal neurons in monkeys' parietal areas 7b and ventral intraparietal area (VIP) (both belonging to PPS coding network) capable of integrating visual and tactile stimuli presented within 30 cm from the animal body-parts, but also from the experimenter's ones. Thus, these neurons where proved to be sensitive not only to events occurring in the animal's PPS but also in others' PPS. A similar overlapping activation pattern in response to stimuli occurring in both one's own and others' peri-hand PPS was observed in human's left ventral pre-motor cortex (vPMC) by Brozzoli et al. (2013). In addition, the authors also found a greater activation of the anterior cingulate cortex (ACC) for events occurring in others' PPS. These findings were extended to the execution of object-directed actions by Livi et al. (2019), who observed that visuo-motor neurons in pre-supplementary motor area F6 fired when the action was executed by the monkey, another agent or simultaneously by both of them. Interestingly, the response elicited by these mirror-like neurons was observed only when the object of the action was located within the monkey's PPS. These results were interpreted as the involvement of an object-mirroring mechanism that recruits self-motor representations to predict others actions and provided empirical evidence for a sensitivity to what happens in the space proximal to others' body.

## 3.3 ANTICIPATING OTHERS' ACTION POSSIBILITIES WITHIN THEIR PPS

Extending the findings presented above, several other studies showed that the brain in capable to detect not only what is currently happening in others' PPS, but also to predict others' action possibilities and integrate the outcomes of their actions. For instance, in a immersive virtual reality study, Iachini and Ruggiero (2021) asked participants to locate a glass with respect to the body of a human avatar (third-person judgment), which was presented while having either its arm free or blocked. Results showed that localization time was longer when the avatar was presented with a blocked arm than a free arm. Authors interpreted such increase as the resultant of a simulation of the avatar's movements by the participants. These findings suggest that individuals take into account others' action possibilities when emitting judgments about objects location with respect to their body. Furthermore, the effect of motor anticipation of others' action possibilities was observed when the avatar was located within a shared space with the participants, but not when it appeared in participants' extrapersonal space. These findings reveal once again the specificity of such mirroring processes to the PPS.

Going one step further, Coello et al. (2018) suggested that, in addition to others' possibilities, individuals are also sensitive to the outcomes of others actions. Similarly to self-generated actions, others' actions can indeed be taken into account to remap PPS. Indeed, Coello et al. (2018) observed that participants' PPS boundary increased after the performance of a stimuli-selection task in collaboration with a confederate. This effect was not observed when facing a passive confederate. In addition, results showed that during the execution of the stimuli-selection task, participants and their confederates tended naturally to split the action space in two, by selecting the stimuli within their own near space, suggesting a tendency to avoid others' space invasion (Coello & Iachini, 2016; Fujii et al., 2009; Szpak et al., 2015; Teneggi et al., 2013). Despite this tendency to exploit a reduced portion of space (to avoid the invasion of others' space), participants' PPS representation was found to extend following the execution of the collaborative action. As a whole, these findings suggest that during the execution of a collaborative action, people extend their PPS representation to include others' near-body space and create a common action space, where both the outcomes of self-generated and others-generated actions are taken into account.

Finally, it is important to note that for this shared space processing to take place, the existence of a common interest towards an object seems crucial. Indeed, a recent study by Patané et al. (2020) revealed that visuo-tactile integration was greater when individuals grasped their own object (I grasp an object belonging to me) or when observing another agent grasping his own object (he grasps an object belonging to him). Such visuo-tactile facilitation did not occur when participants grasped (or observed to grasp) an object that did not belong to the agent of the action (I grasp an object belonging to you/ you grasp an object belonging to me). Nevertheless, it was observed when executing (or observing) a grasping action towards an object belonging to both members of the dyad.

## 3.4 THE SPACE AS CO-CONSTRUCTED INTERFACE FRAMING SOCIAL INTERACTIONS

When sharing a same workspace, a series of mirroring mechanisms are recruited to built a representation of others' PPS and predict their actions towards an object of potential common interest (Fujii et al., 2007; Patané et al., 2020; Pezzulo & Dindo, 2011; Pezzulo et al., 2013). The findings evoked in the previous section suggested that in social context, the sensori-motor and multisensory integration processes underlying PPS perception would undergo a social re-calibration, which would consequently result in the merging of the co-agents space representations to generate a "Shared Action Space" (SAS; Pezzulo et al., 2013).

At this stage of the discussion, one question arises naturally: What are the implications of creating a shared representation of space and taking into account others' space and actions? It has been proposed that this co-constructed shared spatial representation would allow individuals who engage into an interaction to function following a "we mode" (Gallotti & Frith, 2013). This would support the execution of joint or collaborative actions (Pezzulo et al., 2013; Sebanz & Knoblich, 2009) and more generally, facilitate the interactions with the embedding environment. By understanding what others are doing, when and where they are acting and what they will be doing next, individuals would therefore be capable to access other people's internal motivations, intentions and goals. The next section will focus on these aspects.

## 3.5 EXPRESSING AND INFERRING INTENTIONS THROUGH MOTOR ACTIONS

### 3.5.1 *The Paradox of Dr. Jeckyll and Mr Hyde*

For several years, researchers considered that the execution of object-directed motor actions depended on the physical features of the manipulated objects (e.g., size, texture, distance from the body; Eastough & Edwards, 2007; Gentilucci et al., 1991; Paulun et al., 2016) or on the final motor goal of the action chain (e.g., grasping an object to displace it or throw it; Ansuini et al., 2006; Marteniuk et al., 1987). The movement could therefore be subjected to fine motor adjustments in order to adapt to objects' characteristics and to comply with the final goal of the task. More interestingly, it was found that these fine motor variations could be perceived by an observer, who could consequently access relevant information about other agents' motor interactions with surrounding objects (e.g., Cavallo et al., 2016; Elsner et al., 2012; Méary et al., 2005).

Nevertheless, a debate has been going on for several years about the impossibility for an observer to access the higher-order goal subtending the execution of others' actions. Such debate was resumed by the Paradox of Doctor Jekyll and Mister Hyde (Jacob & Jeannerod, 2005). The Doctor Jekyll is the protagonist of the Robert Louis Stevenson's Gothic novel "*The Strange Case of Dr Jekyll and Mr Hyde*" (1886), who struggle with his second evil personality, embodied by the figure of Mister Hyde. Doctor Jekyll is a respected and devoted doctor, while Mister Hyde is a remorseless, sadistic and repugnant man owing his fame to his violent murders. The paradox resides in the fact that when Doctor Jekyll operates a patient, it is impossible for the person being operated to know whether the man in front of him is using the surgical tool with the intention to heal him (reflecting the good intentions of Dr Jekyll) or rather to induce pain (reflecting rather the evil intentions and sadistic pleasure of Mister Hyde). Therefore, despite the action is executed in a similar way (e.g., grasping the scalpel, making an incision), it is impossible to access the truly intentions and motivations underlying the gesture of Doctor Jekyll/Mister Hyde.

### 3.5.2 *The effect of social intention on the execution of object-directed actions*

In the last decades, several studies contradicted the assumption that accessing others truly intentions and motivation is not possible. These studies showed indeed that high-order intentions can actually be expressed through movement execution and that they influence the kinematic features of the movement in a very subtle manner (for a review, see Becchio et al., 2012; Egmose & Køppe, 2017; Krishnan-barman et al., 2017). The studies conducted focused notably on the notion of social intention, which refers to the desire to include another person in the interaction (Jacob & Jeannerod, 2005). Strong empirical evidence showed that when people execute an object-directed action in order for a second person to interact with the same object, the executed movement is characterised by a longer duration and higher amplitude on the vertical plane (Becchio et al., 2008b; Ferri et al., 2011; Manera et al., 2011; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013; Sartori et al., 2009a). Some other studies reported also a different amplitude of finger-thumb aperture and grip opening for gestures executed with a social intention compared to a personal one, being either faster or slower as a function of the task (e.g., Becchio et al., 2008b; Innocenti et al., 2012).

Interestingly, it has been shown that despite the small scale characterising these motor deviants, observers are unconsciously capable of detecting them, using them as a cue to understand and infer others' goals, and responding with an adapted behaviour (Ansuini et al., 2014; Lewkowicz et al., 2013; Rocca & Cavallo, 2020). More specifically, Quesque et al. (2016) showed that the anticipation of social-related motor deviants resulted in a faster reaction of the observer when engaging in the interaction. In their experiment, the authors asked participants to realise a grasp-to-place action, consisting in moving an object from an initial to a final position, in order for either themselves (personal intention) or their confederate (social intention) to realise a second grasp-to place action, consisting in moving the object to a side location. An auditory signal indicated whether the second grasp-to-place action had to be performed by the participant (high pitch) or the confederate (low pitch). The crucial detail of the study was that the participant was informed in advance about whom would had to execute the second-grasp-to place action. This was done by presenting to the participants, trough a pair of headphones, an auditory cue spelling either “You”, “Him” or “Ready” (as control trials) before the first grasp-to-place action. On the contrary, confederates were heard all the time the “Ready” signal, therefore receiving no cues about the execution of the following action.

When analysing the kinematic profile of the first grasp-to-place action, results showed that movements were characterised by a longer reaction time and greater trajectory height when participants knew that the following action would be performed by the confederates, than when knowing that it would have been performed by themselves or when they received neutral information. Interestingly, in that same condition, confederates grasped the object faster compared to the other two conditions, despite having received no prior informative cues. These results were in line with the findings of studies in which participants were proved to be capable of inferring other's social or personal intention from the observation of videos illustrating the execution of object-directed actions (e.g., Lewkowicz et al., 2015). Taken together, these results show that motor deviants due to social intention are automatically perceived during collaborative task and used as cues facilitating the emission of an appropriate motor response by the observers.

In conclusion, the studies presented above indicate that the execution of object-directed action within PPS in social context is the source of informative cues facilitating and rendering the interaction more fluid ans spontaneous. Such cues would consist into a spatio-temporal amplification of the kinematic parameters of the movement. To explain this effect, several authors have evoked the function of rendering such gestures more communicative and to attract the observers' intention. On the basis of such findings, several studies have focused on the factors modulating the understanding of intention through the observation of actions. Nevertheless, to date, several other issues remains open. Indeed, social interaction are complex situations where a multitude of cues co-occur and during which several constraints linked to the interaction itself, the ongoing task and the environment need to be taken into account. In the next chapters, I will describe in more details the unresolved issues and the cues whose effect on the execution of object-directed actions still need to be clarified.

# 4

# RATIONALE OF THE THESIS

In the previous Chapters, I described the neurophysiological and behavioural correlates of PPS coding. In Chapters 1 and 2, I demonstrated that stimuli occurring within this particular space benefit from a multisensory treatment. Such multisensory treatment would allow the anticipation of the moment of contact between the body and the object, and facilitate the execution of purposeful and defensive motor actions. At the end of Chapter 2, I introduced the conceptualisation of PPS as a multiple response-fields representation sensitive to the stimuli value and subtending action selection. In Chapter 3, I showed how PPS is influenced by the presence of other agents, and how the mechanisms underlying the coding of one's own space can also ensure the processing of others' PPS and the actions they perform within it. Furthermore, I also showed how, in a social context, the brain creates a common and shared action space between two individuals engaging in the interaction. Such representation of a common space would be underlain by the sensitiveness to events occurring in others' space and to attribution of a greater salience to objects of common interest. Finally, I mentioned the findings issued from motion-capture studies, showing that when interacting with other agents in a shared space, the intention of an individual to include them in the interaction modifies the spatial and temporal features of the performed motor actions.

In the current Chapter, I will introduce the theoretical assumptions at the basis of my scientific reasoning. I will then expose the rationale of the present thesis, accompanying it by some methodological considerations about the employed paradigms. Finally, I will present the five experimental studies I implemented and offer a general overview of the main objectives pursued in each one of them.

## 4.1 THEORETICAL ASSUMPTIONS

The first theoretical assumption at the basis of the present thesis concerns the choice to focus on the action-related function of PPS, ensuring the guidance of voluntary goal-directed actions towards the objects of interest (de Vignemont & Iannetti, 2015; Hunley & Lourenco, 2018). Therefore, the defensive function ensured by PPS, allowing the maintenance of a buffer safety zone to preserve body's integrity against approaching hazards, will not be considered exhaustively in the present research work. As it recruits specific emotional and physiological mechanisms (e.g., Cartaud et al., 2018; Vieira et al., 2019; Vieira et al., 2017), the defensive function of PPS strays away from the main focus of the current research work.

The second theoretical assumption consists in the conceptualisation of PPS proposed by Bufacchi and Iannetti in their *Action Field Theory of Peripersonal Space* (Bufacchi & Iannetti, 2018, 2019) and by Coello and Cartaud (2021, presented in Section 2.4). According to this conceptualisation, PPS representation would be the resultant of "the integration of a set of [multiple] graded fields describing behavioural relevance of actions aiming to create or avoid contact between objects and the body" (Bufacchi & Iannetti, 2018, p. 1). Additionnally, PPS representation would ensure "the organization of goal-directed behaviours towards stimuli endowed with the highest reward value" (Coello & Cartaud, 2021, p. 1). The very fundamental reasoning at the roots of the present thesis relies on such multi-field, graded representation of PPS, whose construction is determined by the demands of the ongoing action and stimuli value in a given space and time.

Specifically, three main points deriving from this conceptualisation inspired the reasoning at the basis of the current thesis. The first point is the definition of PPS as an area composed of multiple response-fields, instead of a unitary construction. The fields composing PPS correspond to specific portions of space where individuals might execute a given action towards a given stimulus. The second point concerns the hypothesis that PPS would underlie the selection and organisation of motor actions in a given portion of space. According to this more integrative view, PPS would therefore be not only the space where stimuli benefit from an enhanced coding, but also the space where specific motor actions are selected and executed. Finally, the third important point concerns the notion of value attributed to a stimulus of interest, and by extension, to the portion of space occupied by that stimulus. Bufacchi and Iannetti (2019) and Coello and Cartaud (2021) suggested that the value attributed to a given stimulus and a given portion of space in relation to a potential action depends on the influence of several factors, such as the demands of the ongoing motor task and the social context.

## 4.2 THE PRESENT RESEARCH QUESTIONS

In light of these theoretical assumptions, the aim of the present thesis was to assess how motor and social factors contribute to the construction of PPS. Specifically, I wanted to test the general hypothesis that when motor and social factors are concurrently involved, social factors modulate the influence of motor factors on the construction of PPS.

## 4.3 METHODOLOGICAL CONSIDERATIONS

To achieve that purpose and in line with the aforementioned theoretical assumptions, I decided to assessed two main constructs. On the one hand, I assessed *PPS representation*, that I define as the way individuals create a perceptual map of the near-body space. On the other hand, I assessed *PPS exploitation*, that I define as the way individuals use their near-body space during their interactions with objects and confederates. PPS exploitation refers therefore to individuals' behaviour in their near-body space, and more specifically, to the action selection process within PPS.

Through five studies, I assessed PPS representation and exploitation as a function of several motor and social factors. All the five studies required the execution of a motor task in collaboration with another participant. The motor factors consisted in (a) the prospects of rewards when executing an action in a given space, and (b) the physical features of the final spatial target of the motor action. The social factors consisted in (a) the execution of a collaborative action, (b) the degree of involvement into a collaborative task (observing vs. co-acting), (c) the intention to include another person in the interaction, and (d) the influence of communicative cues offered by gaze. In the fifth study, the effect of sharing a physical space during a collaborative motor task was also assessed.

Study 1 and 2 focused on the (a) impact of rewards prospects and the social context, namely (b) the execution of a collaborative task and (c) individuals' involvement degree in the task, on PPS representation and exploitation. In these studies, I employed a paradigm inspired by the one used by Coello et al. (2018), which included the execution of a reachability-judgment task before and after the performance of a stimuli-selection task. The reachability-judgment task was used to estimate the perceived boundary of PPS representation, while the stimuli-selection task offered an easily manipulable setting to quantify and qualify PPS exploitation.

As a complement, Study 3, 4 and 5 were conducted in order to investigate in greater depth the role of motor and social factors on the exploitation of PPS, by analysing the execution of object-directed actions. In that optic, I adopted a motion capture system to analyse the kinematic profile of manual object-directed actions while considering the impact of social intention, namely the intention to include another agent in the interaction with an object of common interest. The effect of social intention was analysed in combination with the effect of (a) the features of the final spatial target of the motor action, (b) the role of eye gaze cues availability and (c) the effect of physically sharing an action space during a collaborative task.

## 4.4 OVERVIEW OF THE STUDIES CONDUCTED

Table 4.1 offers a general overview of the five studies composing the present PhD thesis. Each study will be exposed in a separate chapter of the Experimental Contribution part.

**In Chapter 5** I asked whether, during a collaborative task, the presence of a co-active confederate modulated participants' tendency to exploit the space associated with a higher probability to obtain a reward along with participants' PPS representation.

**In Chapter 6** I explored whether the effect of action rewards and social context on PPS representation and exploitation was modulated by the degree of involvement of individuals in a collaborative task. Specifically, the effect of these two factors was assessed during a collaborative task requiring one participant to act and the other to observe, in order to successively perform the task.

**In Chapter 7** I intended to explore in greater depth the mutual influence of motor and social factors on motor performances within PPS. Specifically, I assessed the combined effects of the physical features of the spatial target and the intention to include another agent in the interaction when concurrently involved in the execution of an object-directed motor task.

**In Chapter 8** I examined the role of social cues provided by eye gaze on the expression and identification of the intention to include another agent in the execution of object-directed actions.

**Finally, in Chapter 9** I attempted to explore whether the effect of social intention observed in face-to-face interactions, where individuals are embedded in a physically shared space, persisted in a situation of co-action mediated by a videoconference system, creating a virtually shared space.

**Table 4.1**
*Overview and Relevant Details of the Five Studies Conducted in the Present Thesis*

| Study | In chapter | Task | Sample size |
|---|---|---|---|
| 1. *Peripersonal space in social context is modulated by action reward, but differently in males and females* | 5 | Reachability-judgment and stimuli-selection task | 40 (20 dyads) |
| 2. *Paying attention to the outcome of others' actions has dissociated effects on observer's peripersonal space representation and exploration* | 6 | Reachability-judgment and stimuli-selection task | 156 (78 dyads) |
| 3. *The combined effects of motor and social goals on the kinematics of object-directed motor action* | 7 | Object-directed action execution | 28 |
| 4. *The contribution of eye gaze and movement kinematics to the expression and the identification of social intention in object-directed motor actions* | 8 | Object-directed action execution | 56 (28 dyads) |
| 5. *"Screens make us less social": The effect of social intention on action kinematics is intrinsically related to the sharing of a same physical space* | 9 | Object-directed action execution | 20 |

# Part II

# EXPERIMENTAL CONTRIBUTION

# 5

# THE EFFECT OF ACTION REWARDS AND SOCIAL CONTEXT ON PPS CONSTRUCTION

## 5.1 RATIONALE OF STUDY 1

The studies presented in previous Chapters showed that the construction of the PPS stems from the integration of different factors. Amongst them, the rewarding outcomes of self-generated and others-generated actions as well as the social context were found to play a crucial role. In this respect, a study conducted by Coello et al. (2018) suggested that realising a task in a shared space in collaboration with a confederate induced a modification of both the representation and exploitation of PPS. Specifically, the study showed that when sharing a common workspace, individuals tend naturally to avoid stimuli located in others' PPS. Despite such avoidance behaviour, PPS representation was found to extend, possibly to encompass the space near the confederate's body. In light of these results, we questioned whether the presence of appealing, rewarding stimuli located in others' PPS would generate a conflict situation where stimuli value and social context prompt different behaviours. The hypothesis tested in this study was the constraints related to the social context would modulate the effect of action rewards on PPS representation and exploitation.

In order to test this hypothesis, we adapted the paradigm of Coello et al. (2018) to concurrently explore the effect of action rewards in space and the constrains related to the social context. Results revealed that participants prioritized the stimuli located in the space associated with higher probability to obtain a reward, but that this effect was modulated by the constrains related to social context. Specifically, the selection of reward-yielding stimuli in the distal space was delayed when it required to invade others' PPS. Furthermore, the distribution of reward-yielding stimuli extended PPS boundaries when biased towards the participants' distal space, but it did not induce a constriction of PPS when biased towards participants' proximal space. From a wider perspective, the present results revealed that the tendency to act towards attractive stimuli in the nearby environment is modulated by the constrains related to the social context (i.e., the preservation of self and other's private space), as well as the integration of others' action outcomes (leading to the creation of a shared action space).

*Note.* The second main outcome of Study 1 was also the effect of gender participants' performance. This results was stressed in the title of the article as well as in the conclusions of the study. Moreover, the original paper took into account the impact of high-order social factors, such as pro-social and cooperative behaviour, and empathy skills. Nevertheless, these results will not be discussed in depth in the present thesis for two reasons. First, such a discussion deviates too much from the main objective of the present research work. Second, gender roles and characteristics have been the focus of recent debates showing that they are a deeply complex issue, influenced by multiple co-occurring factors. Moreover, the studies on gender effect conducted until now are relatively old (most of them date back to 70's and 80's), which means that there are great chances that they are no longer representative of the actual context. In support of this, the study was conducted on a relatively younger population (18–35 years old), for which gender stereotypes and role differences were found to be more and more smother (e.g., Bhatia & Bhatia, 2021).

# Peripersonal space in social context is modulated by action reward, but differently in males and females[1]

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*Published work*

## 5.2 ABSTRACT

PPS is a multisensory representation of the near-body region of space where objects appear at hand. It also represents a buffer zone protecting the body from external threats and, in consequence, it contributes to the organisation of social interactions. However, how the combination of embodied objects processing and constraints inherent to social interactions contributes to PPS representation remains an open issue. By using a cooperative task where two male ($N = 22$) or female ($N = 18$) participants, sharing the same action space, were requested to select a number of stimuli on a touch-screen table, we investigated the effect of non-uniform distribution of reward-yielding stimuli on the selection strategy and perceptual judgments of reachability, used as a proxy of PPS representation. The probability to select a reward-yielding stimulus (50% of the stimuli) was 75% in the proximal space of one of the two confederates. Results showed that participants initially prioritized stimuli in their proximal space but were progressively influenced by the spatial distribution of reward-yielding stimuli, thus invading their confederate's action space when associated with higher probability of reward. The distribution of reward-yielding stimuli led to an increase of reachability threshold, but only when biased towards the participants' distal space. Although the invasion of others' PPS was more pronounced in male participants, the biased distribution of reward-yielding stimuli altered the reachability threshold similarly in males and females. As a whole, the data showed that reward expectations in relation to motor actions influence both PPS exploitation and representation in social context, but differently among males and females.

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[1] It is worth noting that the original title of the article (and the conclusion of the Study) stressed the effect of gender on PPS representation and exploitation, rather than the modulatory role of social context on the effect of action rewards. As indicated in Section 5.1, in the present thesis I will only focus on the finding of a modulatory role of social context on the effect of action rewards when assessing PPS representation and exploitation.

## 5.3 INTRODUCTION

In everyday life, the way humans interact with their environment relies on a series of computations performed by the brain, based on the integration of information related to the body and the space in which it is embedded. This implies that the brain retains a functional representation of the environment, which depends on the current sensorimotor state as well as the outcome of previous interactions with the physical and social context (Grüsser, 1983; Hall, 1966; Previc, 1998). Within this functional representation, the peripersonal space (PPS) specifies the limited space around the body dedicated to the interaction with objects located at hand-reachable distance (Bufacchi & Iannetti, 2018; Coello & Iachini, 2016; de Vignemont & Iannetti, 2015; di Pellegrino & Làdavas, 2015; Rizzolatti et al., 1981). In relation to the linkage between PPS and action, object processing in PPS involves multisensory integration supported by a large subcortical and cortical brain fronto-parietal network implying the motor system (Brozzoli et al., 2011; Cléry et al., 2015; Graziano et al., 1994; Holmes & Spence, 2004; Makin et al., 2007; Serino et al., 2011). In line with this view, Graziano (2018) described multimodal neurons in the premotor cortex that discharge predominantly not only for stimuli near the body, but also for more distant stimuli. Overall, 95% of these neurons code the space within reaching distance (see also di Pellegrino & Làdavas, 2015). Taking advantage of the motor nature of PPS, object perception (Costantini et al., 2010; Spence et al., 2004) and categorization (Blini et al., 2018; Iachini et al., 2017) are facilitated when they are located in PPS.

A number of studies reported that alteration or temporary inhibition of the motor system produces shrinkage of PPS representation (Bartolo et al., 2014; Bassolino et al., 2015; Finisguerra et al., 2015; Toussaint et al., 2018). Furthermore, PPS shrinks when dangerous objects (Coello et al., 2012) or unfamiliar confederates (Teneggi et al., 2013) are located at close distance. In contrast, extending motor abilities through tool-use was found to produce an increase in PPS representation (Bourgeois et al., 2014; Canzoneri et al., 2013; Cardinali et al., 2011; Farne et al., 2005; Iriki et al., 1996; Maravita et al., 2001; Maravita et al., 2002). PPS representation also extends in the presence of appealing stimuli located nearby (Coello et al., 2018) or following positive interaction with a confederate (Coello et al., 2018; Teneggi et al., 2013). Considered as a whole, these data suggest that PPS operates as an interface between perception and action underlying two complementary functions: it subserves goal-directed behaviours towards non-threatening stimuli, and it supports defensive behaviours against threatening and potentially harmful stimuli (Coello et al., 2012; de Vignemont & Iannetti, 2015; di Pellegrino & Làdavas, 2015; Graziano & Cooke, 2006; Hunley & Lourenco, 2018).

The defensive role of PPS makes it thus an important support in the control of social interactions. As evidence, Quesque et al. (2017) demonstrated that tool-use induces not only an enlargement of PPS (Bourgeois et al., 2014), but also an increase of the minimum comfort distance tolerated in dyadic social interactions. Furthermore, physiological responses associated with PPS invasion (Kennedy et al., 2009) were found to be robust predictors of preferred comfort distance in social contexts (Cartaud et al., 2018). As a consequence, individuals with enlarged self-representation of PPS reported a higher rate of social anxiety (Iachini et al., 2015b) and phobia (Lourenco et al., 2011). These results are, therefore, consistent with not only a motor function but also a defensive function of PPS (Cooke & Graziano, 2004), the latter contributing to the organisation of object-directed actions as well as the regulation of the social life (Coello & Iachini, 2016).

In line with the defensive role of PPS, it was found that when performing a cooperative task in a shared workspace, people prioritized stimuli located in their proximal space, avoiding thus to invade others' PPS (Coello et al., 2018). However, despite the division of the workspace in the cooperative task, people showed an expansion of their PPS that was not observed when they performed the task alone or in the presence of a passive confederate. These findings suggest that PPS representation depends on the outcome of both self-executed and observed motor actions in a cooperative, social context. They also reveal that sharing a common workspace induced a natural tendency to favour stimuli located in the proximal space, avoiding thus those located in others' proximal space. Thus, we may surmise that the presence of appealing stimuli in others' PPS represents a conflict situation, where stimuli and space prompt different behaviours.

To investigate this issue, in the present study we tested whether spatially biasing the distribution of reward-yielding stimuli towards one confederate in a dyadic cooperative task induced an invasion of the confederate's PPS. Furthermore, we tested whether such biased distribution of reward-yielding stimuli alters differently PPS representation in the two confederates. Finally, the adjustment of social space was found to be influenced by gender with shorter interpersonal distance usually judged as more comfortable in both males and females when interacting with females as compared to males (Iachini et al., 2014a; Iachini et al., 2016). Accordingly, we compared the effects of biasing the distribution of reward-yielding stimuli towards one of the confederates in both male and female dyads.

## 5.4 METHOD

### 5.4.1 *Participants*

Forty healthy participants voluntarily took part in the experiment (22 males and 18 females, 18–35 years old, *M* = 22.53 years, *SD* = 3.40 years). Participants were recruited in pairs and were not acquainted with their confederate. Each dyad was made up of two male or female participants in order to avoid any possible effect of gender difference in the cooperative task (Iachini et al., 2016). They all had normal or corrected-to-normal visual acuity and were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971, mean laterality quotient = 0.81, *SD* = 0.26). They had no prior detailed information about the hypothesis of the study and gave their informed consent prior to the beginning of the experiment. The protocol received approval by the Institutional Ethics Committee (Ref. Number 2017-7-S52) and was conducted according to the ethical principles of the Declaration of Helsinki (World Medical Association, 2013).

### 5.4.2 *Apparatus and stimuli*

Experimental material, paradigm and procedure were the same as used by Coello et al. (2018). Figure 5.1A provides a schematic illustration of the experimental apparatus. Two participants sat facing each other at opposite sides of a 40” touch-screen table (Samsung SUR40, 109.5 × 70.74 cm). The touch-screen table was placed in the middle of a steel structure, that supported a 30 cm × 100 cm movable rectangular mirror placed 34 cm above the touch-screen table, and a 200 × 150 cm horizontal translucent screen placed 34 cm above the mirror. A video projector (Infocus 3926D) mounted on the ceiling and connected to a computer (Dell 7010) projected a 161 × 118 cm image on the mirror, through the translucent screen located 79 cm below the video projector. Depending on the task, participants were requested to process the stimuli projected on the mirror (reachability-judgment task), or directly displayed by the touch-screen table (stimuli-selection task).

In the *reachability-judgment task*, 51 grey stimuli (1 cm-diameter dots), ranging from 0 cm to 100 cm away from the head position of the participants (mean inter-target distance of 2 cm), were projected at the level of the touch-screen table, by the way of the optical projection of the image displayed on the mirror through the translucent screen (Figure 5.1B). The stimuli were randomly displayed for 250 ms and presented four times each, for thus a total of 204 trials (51 distances × 4 repetitions). While performing the task, a black sheet covered the touch-screen table in order to avoid any luminous source that could interfere with the perception of the visual stimuli.

In the *stimuli-selection task*, 32 grey stimuli (2.7 cm-diameter dots) were randomly displayed on the black background of the 40” (1920 × 1080 px) touch-screen table (active area of 88.56 × 49.81 cm) according to a non-visible distribution grid (Figure 5.1C). The grid was composed of 42 non-visible cells (6 rows × 7 columns) that covered the whole touch-screen table. When positioned at the centre of the cells, the inter-stimuli distance was 12.65 cm (274 px) along the $x$ axis and 8.30 cm (180 px) along the $y$ axis. In each block of stimuli selection, the 32 grey stimuli were displayed at random locations (from 0 to 60 pixels from the centre in the $[x, y]$ directions) in randomly selected cells, thus leaving 10 cells empty. The configuration of the set of stimuli changed in each block, which gave the feeling of a sequence of random distributions. Participants selected each stimulus by touching it on the screen with the right index finger, resulting in a stimulus colour change. If the stimulus turned to green (50% of the stimuli), a sound of clinking coins was played and participants gained one point (reward-yielding stimulus). If the stimulus turned to red (50% of the stimuli), a buzzing sound was played and participants gained no point (no reward-yielding stimulus). The probability to select a green reward-yielding stimulus was differently distributed according to the location of the participants in the dyads. For 50% of the participants ($G_{near}$), the probability of selecting a reward-yielding stimulus was 75% in the near space (rows 1, 2 and 3) and 25% in the far space (rows 4, 5 and 6). For the other 50% of the participants ($G_{far}$), the probability of selecting a reward-yielding stimulus was 75% in the far space (rows 4, 5 and 6) and 25% in the near space (rows 1, 2 and 3; see Figure 5.1C). Participants belonging to the $G_{near}$ or $G_{far}$ group were randomly placed in either side of the touch-screen table. Each dyad performed 34 blocks of stimuli selection, each block including 12 selections of stimuli (6 per participant, alternating at each selection). Two digital counters were displayed along the proximal edge of the touch-screen table, in the middle, so that each participant of the dyads could check for the score accumulated throughout the task.

### 5.4.3 *Procedure*

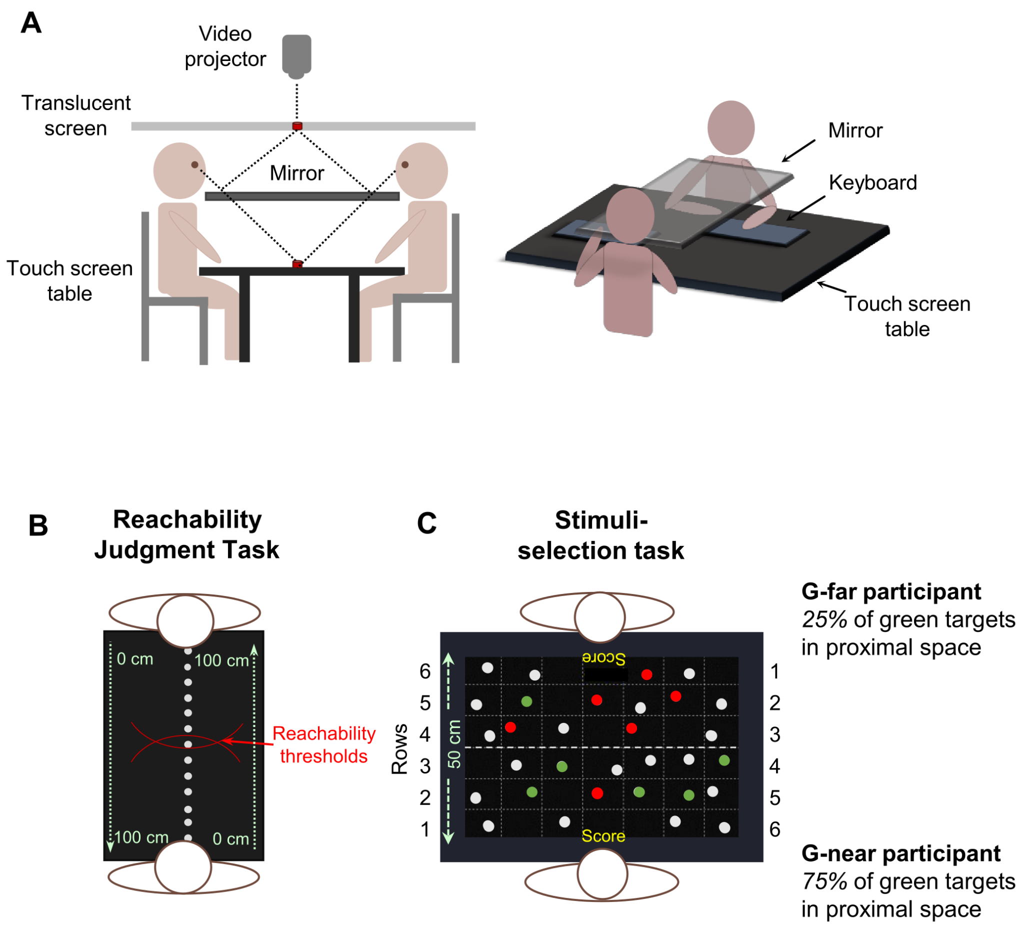
To begin with, participants of each dyad completed the written consent and the Edinburgh Handedness Inventory (Oldfield, 1971). The two participants were then seated in a dark room at opposite sides of the touch-screen table (inter-head distance of 1 m) and received the instructions relating to the two tasks. The experimental session was composed of three subsequent phases: (a) A pretest phase in which participants performed the reachability-judgment task; (b) a test phase in which participants performed the stimuli-selection task; (c) a posttest phase in which participants performed the reachability judgment task again. The whole experimental session lasted about one hour.

In the *reachability-judgment task* (pretest and posttest phases), the two participants of the dyads were requested to estimate if the stimulus presented could be reached or not with the right hand, but without performing any actual movement. The two participants saw the same stimulus but performed the task individually, providing thus simultaneously reachable/unreachable responses on different keyboards with their left index and middle fingers. Following a short practice session (5 stimuli), each participant judged the reachability of 204 stimuli in both sessions (pretest and posttest). Inter-stimuli interval lasted 1.5 s, during which participants provided their responses. A short break period of 60 s was provided halfway in each session.

In the *stimuli-selection task*, the mirror, the two keyboards and the black sheet covering the touch-screen table were removed. In order to highlight the cooperative aspect of the stimuli-selection task, the latter was presented to participants as a game that had to be played together. The aim was to get a maximum score by cooperatively cumulating as many points as possible by finding as many green (reward-yielding) stimuli as possible. For this purpose, they alternatively selected with their right finger 12 stimuli out of the 32 displayed on the screen. Participants in the $G_{near}$ group always performed the first selection in order to standardize the procedure. Overall, each participant selected a total of 204 stimuli leading to a total of 408 stimuli per dyad (2 participants

**Figure 5.1**

*Schematic Illustration of the Experimental Apparatus (A), and Stimuli Used in the Reachability-Judgment (B) and Stimuli-Selection (C) Tasks*



*Note.* According to the group, the probability of selecting a (green) reward-yielding stimulus was 75% in the participant's or their confederate's proximal space.

× 6 stimuli × 34 blocks of trials). Participants had no right to verbally or visually communicate during the whole experiment. At the end of the experiment, participants responded to two individual social characteristics questionnaires. First, the Interpersonal Reactivity Index (IRI, French version by Guttman  Laporte, 2000; see Appendix **??**), assessing through four subscales cognitive empathy (Perspective Taking, Fantasy) and affective empathy (Empathic Concern, Personal distress). Second, the Social Value Orientation Slider Measure (SVO-Slider Measure, French version; Murphy et al., 2011, see Appendix **??**), assessing people's prosocial tendency, which has been found to influence the propensity to cooperate (Zeelenberg et al., 2008). Finally, we checked in a post-experiment debriefing that none of the participants were aware of the hypotheses tested, which was the case.

### 5.4.4 *Data and statistical analysis*

Matlab software (R2017a) was used for the implementation of the tasks as well as for data collection and analysis. Statistical analyses were carried out with R version 3.3.2 (R Core Team, 2017) and R Studio version 1.0.136. Concerning the *reachability-judgment task*, the perceived boundary of PPS (reachability threshold) was determined using the maximum likelihood fit procedure based on second-order derivatives (quasi-Newton method) to obtain the logit regression model that best fitted the dichotomous responses (reachable/ unreachable) provided by participants for each of the 51 distances of stimuli (Bourgeois & Coello, 2012). The logit regression model was obtained by employing the following equation:

$$Y = \frac{exp^{(\alpha+\beta*X)}}{1+exp^{(\alpha+\beta*X)}} \tag{5.1}$$

In this model, $X$ relates to the distance at which the stimulus appeared, while $Y$ corresponds to the answer given by the participants. Reachability threshold corresponds to - $\alpha/\beta$, which defines the critical value of $X$ marking the transition between the response "reachable" and "unreachable" (i.e., the boundary of PPS). Individual reachability thresholds were corrected according to the actual arm length by subtracting arm length (cm) to the critical value of $X$. Reachability thresholds were computed separately for pretest and posttest. A reachability threshold in the posttest similar to that in the pretest (posttest-pretest difference $= 0$) indicated no change of PPS representation. A higher reachability threshold in the posttest (posttest-pretest difference $> 0$) indicated a shift of reachability threshold away from the participant (i.e., extension of PPS representation), while a lower reachability threshold (posttest-pretest difference $< 0$) denoted a shift of reachability threshold towards the participant (i.e., shrinkage of PPS representation). We analysed the perceived change of reachability thresholds (posttest-pretest difference) through a Session (Pretest, Posttest) × Group ($G_{near}$, $G_{far}$) × Gender (Male, Female) analysis of variance (ANOVA), with Group and Gender as between-subject factors. The goodness of fit of the logistic regression was estimated through McFadden's pseudo-$R$ squared.

Concerning the *stimulus-selection task*, we computed the number of stimuli selected in the distal space (rows 4–6 for $G_{near}$ and $G_{far}$) for each participant and for each block. For the data analyses described hereafter, non-parametric statistical tests were used as the number of comparisons did not allow the validation of the necessary assumptions (normality, homoscedasticity) to use parametric tests. Specifically, we applied permutation-based ANOVA following Manly's method (Manly, 2018), setting the number of permutations at 99,999. Post-hoc comparisons were assessed through permutation tests based on 9999 Monte-Carlo resampling, using the independence_test function of the "coin" package implemented on R (Hothorn et al., 2008).

First, we calculated the average number of distal stimuli selected, all blocks considered together, in order to assess the general tendency to invade the confederate's space. Statistical analyses were carried out using a permutation-based ANOVA with

Group ($G_{near}$, $G_{far}$) and Gender (Female, Male) as between-subject variables. Second, we compared the average number of distal stimuli selected in the first and last three blocks to account for an eventual change in selection strategy during the selection task. We applied permutation-based ANOVA with Block (First, Last) as within-subject variable, and Group ($G_{near}$, $G_{far}$) and Gender (Male, Female) as between-subject variables. Third, in order to assess the precise moment at which a change in the participants' strategy occurred, we compared the number of distal stimuli selected across all blocks in $G_{near}$ and $G_{far}$, taking gender into account. We performed permutation-based multiple comparisons for each block of trials, comparing first $G_{near}$ vs. $G_{far}$ performances, and males' vs. females' performances separately for $G_{near}$ and $G_{far}$. We further conducted linear regression analysis and applied $F$ test to test the overall significance of the model, in order to account for any global change in the performance across blocks, depending on the gender.

Furthermore, in line with Coello et al. (2018)'s analysis, we calculated for each participant (a) the difference between posttest and pretest reachability estimates, (b) the average amplitude of selection actions toward the stimuli across all blocks and (c) the number of rewards obtained in the distal space. Correlations between the two latter variables and the individual posttest–pretest difference in reachability threshold were tested (Spearman's rank correlation coefficient), considering gender and group together, in order to evaluate whether the reported change of PPS representation was related to the amount of rewards obtained rather than to the amplitude of motor performances. In addition, we applied a $z$ test to compare the observed percentage of reward-yielding stimuli selected in $G_{near}$ and $G_{far}$ to the percentage that participants would have obtained if they had only selected stimuli located in their respective proximal space.

Finally, in order to analyse the results at the IRI scale, we computed the score obtained by the participant at each of the four subscales of the questionnaire: the Perspective Taking and Fantasy subscales (relating to cognitive component of empathy) and the Empathic Concern and Personal Distress subscales (accounting for the affective component of empathy). The Perspective Taking subscale evaluates the ability to adopt other people's psychological point of view. The Fantasy subscale measures the inclination to get involved in fictional situations and identify with fictional characters in books, play or movies. The Empathic Concern subscale refers to the propensity to be concerned and feel compassion for other people. The Personal distress subscale measures the tendency to experience distress or discomfort in response to others' emotional distress. As regards the SVO-Slider Measure, we analysed the first six primary items (discarding the nine secondary items as being less essential according to our hypotheses and not calculable for every participant). The score at the SVO-Slider Measure is provided in angle expressed in degrees: An angle less than -12.04° indicates the tendency to be competitive; between -12.04° and 22.45° the propensity to be individualist; between 22.45° and 57.15° the tendency to be prosocial; and greater than 57.15° the propensity to be altruistic. In order to test the differences in individual social characteristics between females and males, we statistically compared the scores at the four IRI subscales and at the Primary Items using the Mann–Whitney $U$ test for two independent samples, with Gender (Female, Male) as between-subject factor.

For parametric ANOVA designs, the normality assumption was verified using the Shapiro–Wilk test and checking the skewness and kurtosis values of the distributions. The homogeneity of the variance–covariance matrix was verified using the Box's $M$ test and the sphericity assumption was verified using Mauchly's sphericity test. Effect sizes were indexed using partial eta-squared ($\eta_p^2$). Post-hoc comparisons were performed using Tukey's HSD test. Significance threshold was set at $\alpha = .050$ for all statistical tests and at $\alpha = .010$ for tests validating the assumptions necessary to the application of parametric tests (normality, sphericity, homogeneity of variance–covariance matrices).

## 5.5 RESULTS

### 5.5.1 *Reachability-judgment task*

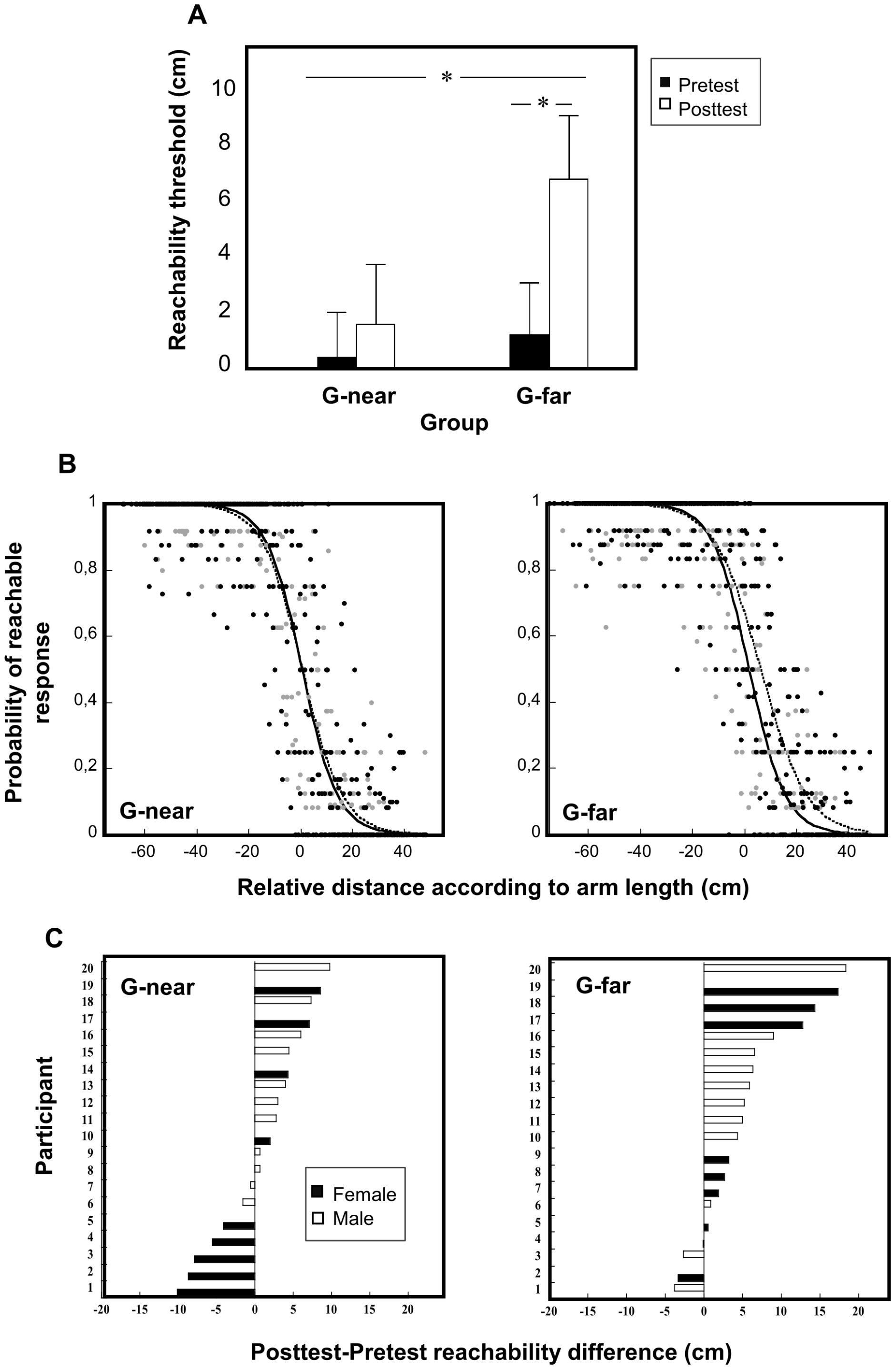
As regards the goodness of fit in logistic regressions, Mac-Fadden's pseudo-$R$ squared was on average .62 ($SD = 0.16$). In the pre-test, participants overestimated their actual reachability threshold on average by 1.28 cm ($SD = 6.70$), which corresponded to an overestimation of arm-length of 2% ($M = 72.50$ cm, $SD = 5.00$). Statistical analysis revealed a significant Session × Group interaction ($F_{(1,36)} = 5.19$, $p = .029$, $\eta_p^2 = 0.13$; see Figure 5.2A). Pairwise comparisons showed that reachability threshold increased in the posttest relative to the pretest in $\mathrm{G}_{far}$ (pretest: $M = 1.21$ cm, $SD = 7.74$ and posttest: $M = 6.37$ cm, $SD = 9.40$, $p = .003$) but not in $\mathrm{G}_{near}$ (pretest: $M = 0.45$ cm, $SD = 6.77$ and posttest: $M = 1.45$ cm, $SD = 8.97$, $p = .878$, see Figure 5.2B). Neither the Gender principal effect ($F_{(1,36)} = 0.52$, $p = .475$) nor the interaction effects Gender × Group ($F_{(1,36)} = 1.32$, $p = .258$), Session × Gender ($F_{(1,36)} = 1.16$, $p = .288$) and Gender × Group × Session ($F_{(1,36)} = 1.94$, $p = .172$) were significant. These results suggest that the reachability threshold was not statistically different between females and males in $\mathrm{G}_{near}$ (females: $M = -0.78$ cm, $SD = 5.81$ and $M = -2.37$ cm, $SD = 8.75$ for pretest and postest, respectively; males: $M = 1.45$ cm, $SD = 7.59$ cm and $M = 4.58$ cm, $SD = 8.22$ for pretest and postest, respectively) as well as in $\mathrm{G}_{far}$ (females: $M = 1.62$ cm, $SD = 6.47$ and $M = 7.11$ cm, $SD = 8.30$, for pretest and postest, respectively; males: $M = 0.87$ cm, $SD = 8.95$ and $M = 5.76$ cm, $SD = 10.57$, for pretest and postest, respectively). Figure 5.2C shows individual posttest–pretest reachability threshold differences as function of gender and group.

### 5.5.2 *Stimuli-selection task*

For a descriptive purpose, we calculated the frequency of stimuli selected at each location, by dividing the number of times each cell with a stimulus was selected on the touch-screen table by the number of times this cell contained a stimulus. Figure 5.3A and B shows the frequency of stimuli selected at each location according to the group

**Figure 5.2**

*Results of the Reachability-Judgment Task*



*Note.* A) Mean relative pretest and posttest reachability threshold according to arm length (cm) as a function of the Group ($G_{near}$, $G_{far}$). Error bars represent standard errors. Stars indicate significant differences between groups in the posttest–pretest reachability threshold change ($*p < .050$). B) Group logit fit as function of Group ($G_{near}$, $G_{far}$) and Session (Pretest, Posttest). Dots represent individual answers for both female and male participants. C) Individual posttest–pretest differences of reachability threshold (cm) as a function of the Group ($G_{near}$, $G_{far}$). Positive and negative signs indicate, an expansion and shrinkage of PPS representation respectively.

**Table 5.1**

*Total Number of Stimuli Selected during the Stimuli-Selection Task in Each Row as a Function of Group (G$_{near}$, G$_{far}$) and Gender (Female, Male), and Percentage of Stimuli Selected as a function of the Area (Proximal, Central, Distal)*

| Group | Gender | Row | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| G$_{near}$ | Female | 488 | 615 | 487 | 176 | 50 | 20 |
| | | 60 % | | 36 % | | 4 % | |
| | Male | 751 | 690 | 476 | 192 | 91 | 44 |
| | | 64 % | | 30 % | | 6 % | |
| G$_{far}$ | Female | 278 | 431 | 529 | 351 | 173 | 74 |
| | | 39 % | | 48 % | | 13 % | |
| | Male | 258 | 347 | 470 | 493 | 419 | 266 |
| | | 27 % | | 43 % | | 30 % | |

*Note.* Proximal Area: rows 1–2; Central Area: rows 3–4; Distal Area: rows 5–6. The percentages are calculated in relation to the total number of stimuli selected, equal to 1836 for females (6 stimuli × 34 blocks × 9 participants) and to 2244 for males (6 stimuli × 34 blocks × 11 participants).

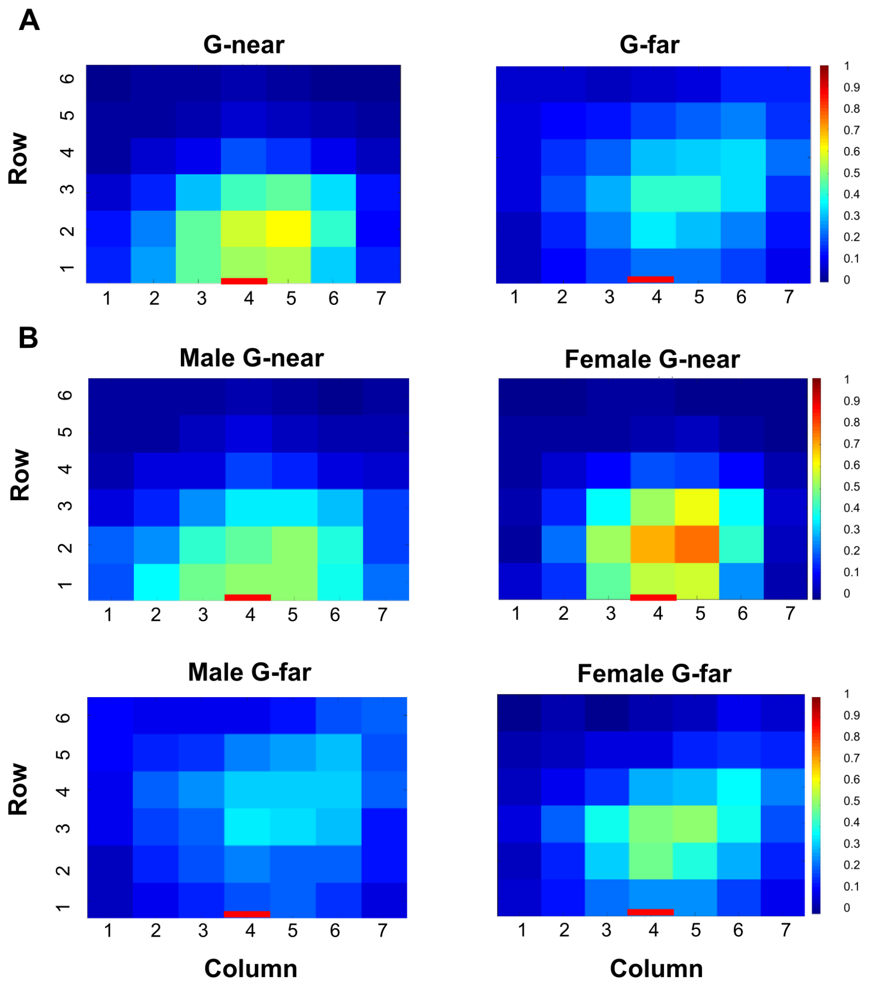
and gender and offers a visualization of the touch-screen table areas where participants acted predominantly. Table 5.1 shows the number of stimuli selected by females and males, in both G$_{near}$ and G$_{far}$, as well as their percentage relative to the total number of stimuli selected, after pooling rows 1–2 (proximal area), rows 3–4 (central area) and 5–6 (distal area).

In order to better account for the invasive behaviour characterising the participants, we contrasted the number of distal stimuli (localised beyond the middle of the table) selected in G$_{near}$ and G$_{far}$, taking into account the gender. Permutation-based ANOVA revealed a significant Group ($p < .001$) principal effect. Post-hoc comparisons showed that as a whole, the number of distal stimuli selected in G$_{far}$ ($M$ = 86.25, $SD$ = 40.76) was broader than the number of distal stimuli selected in G$_{near}$ ($M$ = 28.65, $SD$ = 16.84, $z$ = -4.30, $p < .001$). The Gender principal effect was also significant ($p$ = .011), as well as the Group × Gender interaction ($p$ = .023; see Figure 5.4A). Post-hoc comparisons relating to the interaction revealed that in G$_{near}$, no statistically significant difference emerged between males and females ($M$ = 29.73, $SD$ = 14.24 and $M$ = 27.33, $SD$ = 20.41, respectively; $z$ = -0.31, $p$ = .763), the former crossing the middle line 15% of the time and the latter 13%. In G$_{far}$, male participants selected on average more distal stimuli than female participants ($M$ = 106.27, $SD$ = 34.91 and $M$ = 61.78, $SD$ = 34.62, respectively; $z$ = - 2.43, $p$ = .012), crossing the middle of the screen and invading their confederate's space 52% of the time compared to 30% in females.

Regarding the change of selection performance between the beginning and the end of the stimuli-selection task, statistical analysis showed a significant Block × Group interaction ($p$ = .001). As revealed by post-hoc comparisons, the number of distal stimuli selected was, on average, statistically higher in the last blocks compared to the first blocks in G$_{far}$ ($M$ = 3.30, $SD$ = 1.73 and $M$ = 1.78, $SD$ =1.63, respectively; $z$ = -2.62, $p$ = .004), but not in G$_{near}$ ($M$ = 0.06, $SD$ = 0.78 and $M$ = 1.08, $SD$ =

**Figure 5.3**

*Density Maps of the Targets Selected by Participants in the Stimuli-Selection Task*



*Note.* A) Density maps of the targets selected by the participants in G$_{near}$ and G$_{far}$ in the stimuli-selection task. The rectangles represent the distribution grid composed of 42 cells. The frequency of selection of a given stimulus location is associated with a colour bar ranging from blue (rare selection) to red (frequent selection). The plots represent participants' performances according to their position on the touch-screen table: rows 1, 2 and 3 correspond to G$_{near}$'s proximal space and rows 4, 5, 6 to G$_{far}$'s proximal space. B) Density maps of the stimuli selected by male and female participants in G$_{near}$ and G$_{far}$. The red bar indicates the participants' location.

0.92, respectively; $z$ = 0.19, $p$ = .445). Furthermore, statistical analysis revealed a gender principal effect ($p$ = .021), with males globally selecting more distal stimuli than females ($M$ = 2.19, $SD$ = 1.73 and $M$ = 1.32, $SD$ = 1.23, respectively, $z$ = -2.42, $p$ = .017). This effect was modulated by neither the Group nor the Block (Gender × Group × Block: $p$ = .593; Gender × Group: $p$ = .057; Gender × Block: $p$ = .456).

When analysing the change of selection performance across all the blocks, permutation tests showed that $G_{near}$ and $G_{far}$'s strategy diverged consistently from the 12th block (see Figure 5.4B). Concerning the gender effect (see Figure 5.4C), in $G_{near}$ regression analysis revealed that male participants selected progressively more proximal stimuli across the blocks ($R$ = -.75, $F_{(1,32)}$ = 41.73, $p$ < .001), which was not observed in female participants ($R$ = -.13, $F_{(1,32)}$ = 0.53, $p$ = .473). However, no specific pattern in the change of strategy across block emerged from permutation tests when contrasting males and females. Within $G_{far}$, regression analysis showed that both female and male participants selected more distal stimuli across blocks (respectively, $R$ = .78, $F_{(1,32)}$ = 51.77, $p$ < .001 and $R$ = .82, $F_{(1,32)}$ = 65.15, $p$ < .001), although only male participants consistently selected an average of more than 50% of the stimuli in the distal space (see Figure 5.4C). In line with these results, permutation tests revealed that male participants' strategy statistically differed from the female participants' one from the third block on and repeatedly all along the blocks. This suggested a tendency for male participants to invade their confederate's space sooner and more consistently than female participants. All $Z$ and $p$ values for each block permutation test are reported in Table 5.2.

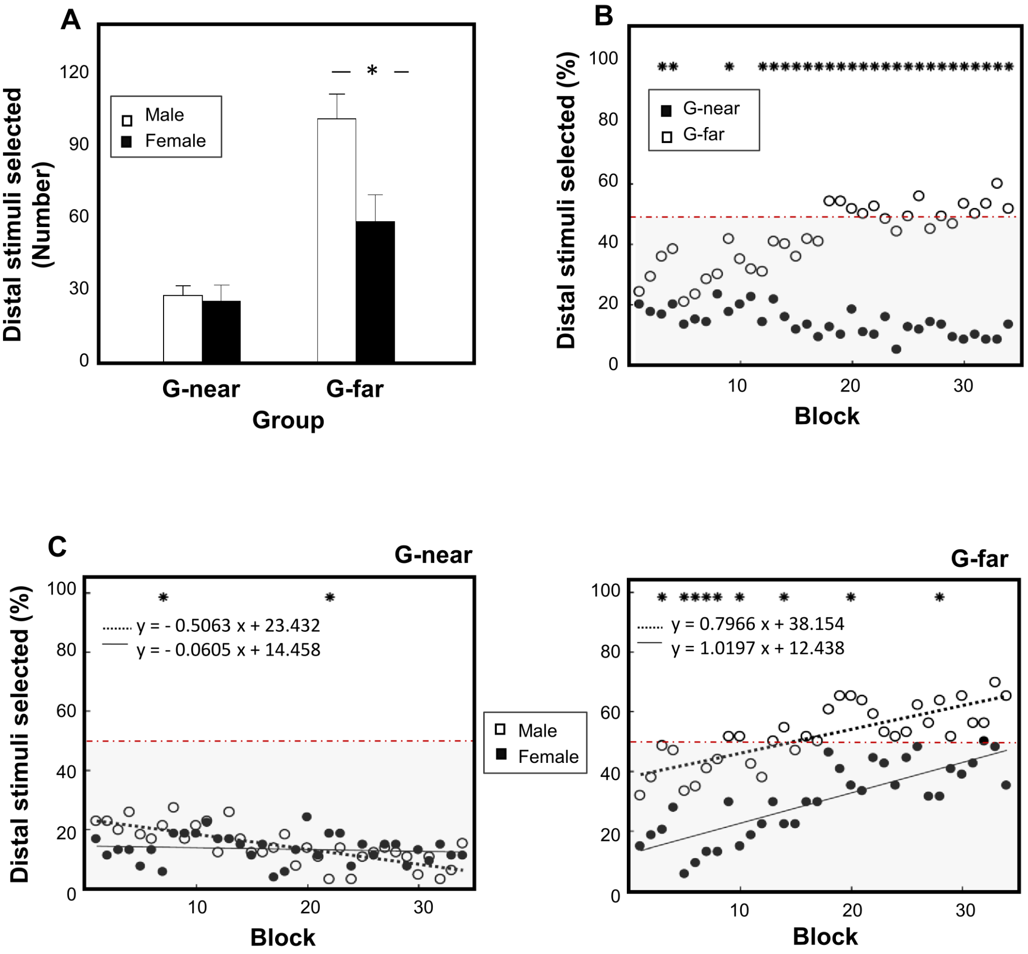
In agreement with the design of the experiment, and participants' natural preference for proximal space, results showed that the number of reward-yielding stimuli obtained depended on the group, with $G_{near}$ obtaining 2840 (70%) and $G_{far}$ 2095 (51%) reward-yielding stimuli. This distribution was statistically different from the theoretical distribution (75% for $G_{near}$ and 25% for $G_{far}$) that would result if participants had selected stimuli only in their proximal space ($z$ = -7.38, $p$ < .001 for $G_{near}$, $z$ = 26.85, $p$ < .001 for $G_{far}$).

### 5.5.3 *Relation between change in reachability threshold, reaching actions' amplitude and amount of rewards obtained*

Correlation analysis indicated that the reported change of PPS representation was related to the amount of rewards obtained rather than to the change in the characteristics of the motor activity. Indeed, when correlating the posttest–pretest difference of reachability threshold to the number of rewards obtained by each participant, gender and group considered together, Spearman's correlation coefficient between the two variables was 0.33 ($p$ = .039) when considering the rewards obtained after selecting stimuli in the distal space. In contrast, when correlating the posttest–pretest difference in reachability threshold to the average amplitude of the selection actions, the Spear-

**Figure 5.4**

*Number and Percentage of Distal Stimuli Selected on Average by All Participants During the Stimuli-Selection Task*



*Note.* a) Number of distal stimuli selected on average by males and females in $G_{far}$ and $G_{near}$. Error bars represent standard errors. Stars indicate significant differences ($p < .050$). b) Percentage of distal stimuli selected across the 34 blocks in $G_{far}$ and $G_{near}$. The two groups diverged consistently from the 12th block on. c) Percentage of distal stimuli selected across the 34 blocks by male and female participants in $G_{far}$ and $G_{near}$. For $G_{far}$ and $G_{near}$. The regression equations express the linear relationship between the blocks and the percentage of distal stimuli selection is displayed. Stars indicate significant differences revealed by permutation tests. The grey area in the graph represents the proximal area on the touch-screen table, and the horizontal red dotted line indicates when the stimuli are equivalently selected in the proximal space and in the distal space

**Table 5.2**

*Detailed Results of Multiple Comparisons Based on Permutation Tests (z, p, % of distal stimuli) for $G_{far}$ vs. $G_{near}$, Females vs. Males in $G_{far}$, Females vs. Males in $G_{far}$*

| | Gfar vs. Gnear | | | | Females vs. Males - Gfar | | | | Females vs. Males – Gnear | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Distal stimuli (%) | | | | Distal stimuli (%) | | | | Distal stimuli (%) | |
| Block | *z* | *p* | Gfar | Gnear | *z* | *p* | Females | Males | *z* | *p* | Females | Males |
| 1 | 0.47 | .711 | 24.17 | 20.00 | -1.14 | .276 | 14.81 | 31.82 | -0.58 | .648 | 16.67 | 22.73 |
| 2 | 1.39 | .203 | 29.17 | 17.50 | -1.35 | .201 | 18.52 | 37.88 | -1.35 | .246 | 11.11 | 22.73 |
| 3 | 2.42 | .017 | 35.83 | 16.67 | -2.18 | .033 | 20.37 | 48.48 | -0.93 | .495 | 12.96 | 19.70 |
| 4 | 2.18 | .033 | 38.33 | 20.00 | -1.31 | .214 | 27.78 | 46.97 | -1.91 | .078 | 12.96 | 25.76 |
| 5 | 1.12 | .328 | 20.83 | 13.33 | -2.44 | .015 | 5.56 | 33.33 | -1.51 | .162 | 7.41 | 18.18 |
| 6 | 1.21 | .287 | 23.33 | 15.00 | -2.13 | .036 | 9.26 | 34.85 | -0.54 | .636 | 12.96 | 16.67 |
| 7 | 1.90 | .071 | 28.33 | 14.17 | -2.10 | .043 | 12.96 | 40.91 | -2.81 | .004 | 5.56 | 21.21 |
| 8 | 0.79 | .493 | 30.00 | 23.33 | -2.17 | .027 | 12.96 | 43.94 | -0.95 | .380 | 18.52 | 27.27 |
| 9 | 2.94 | .004 | 41.67 | 17.50 | -1.72 | .110 | 29.63 | 51.52 | 0.25 | .830 | 18.52 | 16.67 |
| 10 | 1.75 | .097 | 35.00 | 20.00 | -2.49 | .013 | 14.81 | 51.52 | -0.34 | .835 | 18.52 | 21.21 |
| 11 | 1.16 | .299 | 31.67 | 22.50 | -1.80 | .070 | 18.52 | 42.42 | -0.06 | 1.000 | 22.22 | 22.73 |
| 12 | 2.09 | .042 | 30.83 | 14.17 | -1.34 | .202 | 22.22 | 37.88 | 0.46 | .740 | 16.67 | 12.12 |
| 13 | 2.16 | .038 | 40.83 | 21.67 | -1.45 | .157 | 29.63 | 50.00 | -0.96 | .383 | 16.67 | 25.76 |
| 14 | 2.65 | .008 | 40.00 | 15.83 | -2.24 | .027 | 22.22 | 54.55 | -0.22 | .854 | 14.81 | 16.67 |
| 15 | 2.81 | .004 | 35.83 | 11.67 | -1.77 | .095 | 22.22 | 46.97 | -0.15 | 1.000 | 11.11 | 12.12 |
| 16 | 2.93 | .004 | 41.67 | 13.33 | -1.47 | .176 | 29.63 | 51.52 | 0.30 | .860 | 14.81 | 12.12 |
| 17 | 3.08 | .001 | 40.83 | 9.17 | -1.20 | .239 | 29.63 | 50.00 | -1.50 | .208 | 3.70 | 13.64 |
| 18 | 3.98 | .000 | 54.17 | 12.50 | -1.08 | .308 | 46.30 | 60.61 | -1.30 | .259 | 5.56 | 18.18 |
| 19 | 4.35 | .000 | 54.17 | 10.00 | -1.78 | .081 | 40.74 | 65.15 | 0.95 | .381 | 12.96 | 7.58 |
| 20 | 3.52 | .000 | 51.67 | 18.33 | -2.26 | .028 | 35.19 | 65.15 | 1.20 | .256 | 24.07 | 13.64 |
| 21 | 3.63 | .000 | 50.00 | 10.83 | -1.82 | .086 | 33.33 | 63.64 | 0.08 | 1.000 | 11.11 | 10.61 |
| 22 | 3.98 | .000 | 52.50 | 10.00 | -0.96 | .385 | 44.44 | 59.09 | 2.20 | .023 | 18.52 | 3.03 |
| 23 | 3.59 | .000 | 48.33 | 15.83 | -0.83 | .443 | 42.59 | 53.03 | 0.59 | .693 | 18.52 | 13.64 |
| 24 | 3.84 | .000 | 44.17 | 5.00 | -1.03 | .344 | 35.19 | 51.52 | 1.02 | .459 | 7.41 | 3.03 |
| 25 | 3.63 | .000 | 49.17 | 12.50 | -0.55 | .608 | 44.44 | 53.03 | 0.71 | .578 | 14.81 | 10.61 |
| 26 | 4.26 | .000 | 55.83 | 11.67 | -1.06 | .320 | 48.15 | 62.12 | -0.13 | 1.000 | 11.11 | 12.12 |
| 27 | 3.12 | .002 | 45.00 | 14.17 | -1.64 | .114 | 31.48 | 56.06 | 0.13 | 1.000 | 14.81 | 13.64 |
| 28 | 3.72 | .000 | 49.17 | 13.33 | -2.32 | .021 | 31.48 | 63.64 | 0.36 | .854 | 14.81 | 12.12 |
| 29 | 4.18 | .000 | 46.67 | 9.17 | -0.88 | .423 | 40.74 | 51.52 | -0.56 | .771 | 7.41 | 10.61 |
| 30 | 4.46 | .000 | 53.33 | 8.33 | -2.02 | .051 | 38.89 | 65.15 | 1.36 | .301 | 12.96 | 4.55 |
| 31 | 4.12 | .000 | 50.00 | 10.00 | -1.01 | .377 | 42.59 | 56.06 | -0.20 | 1.000 | 9.26 | 10.61 |
| 32 | 4.28 | .000 | 53.33 | 8.33 | -0.44 | .715 | 50.00 | 56.06 | 1.66 | .184 | 14.81 | 3.03 |
| 33 | 4.70 | .000 | 60.00 | 8.33 | -1.61 | .133 | 48.15 | 69.70 | 0.82 | .611 | 11.11 | 6.06 |
| 34 | 3.62 | .000 | 51.67 | 13.33 | -1.95 | .060 | 35.19 | 65.15 | -0.47 | .713 | 11.11 | 15.15 |

man's correlation coefficient between the two variables was 0.29 and not significant ($p$ = .067).

### 5.5.4 *Individual social characteristics measures*

As regards the results in the IRI scale, statistical analysis did not show any significant difference between female and male participants at the Perspective Taking subscale ($U$ = 710, $p$ = .214; $M$ = 25.7, $SD$ = 4.07 for females and $M$ = 25.1, $SD$ = 4.20 for males), Fantasy subscale ($U$ = 718, $p$ = .238; $M$ = 26.8, $SD$ = 5.37 for females and $M$ = 26.2, $SD$ = 5.64 for males) and Empathic Concern subscale ($U$ = 774, $p$ = .433; $M$ = 26.0, $SD$ = 4.17 for females and $M$ = 26.0, $SD$ = 3.55 for males). On the contrary, statistical analysis showed a significant gender difference at the Personal Distress subscale ($U$ = 234, $p$ < .001), with females reporting a higher score than males ($M$ = 25.2, $SD$ = 4.22 and $M$ = 18.6, $SD$ = 4.79, respectively).

As regards the results at SVO-Slider Measure, four participants (3 females and 1 male) resulted individualistic (angle comprised between -12.04° and 22.45°), while the rest of participants resulted prosocial (angle comprised between 22.45° and 57.15°). Furthermore, males showed higher angles than females ($M$ = 35.0, $SD$ = 7.37 and $M$ = 31.1, $SD$ = 9.92, respectively), resulting statistically more prosocial than females ($U$ = 610, $p$ = .037).

## 5.6 DISCUSSION

The aims of the present study were to investigate (a) how two face-to-face confederates actively explore a shared space when the constraints related to actions' outcome prompt the invasion of one of the confederate's space; (b) how does such behaviour alter participants' PPS representation; and (c) whether the observed experimental effects are modulated by the participants' gender. For this purpose, we probed participants' PPS representation through a reachability-judgment task before and after taking part in a stimuli-selection task performed cooperatively with a confederate. The experimental manipulation consisted in increasing for one participant and decreasing for the other participant of a dyad the probability to select a reward-yielding stimulus when acting in the proximal space.

The first important result obtained in the present study concerns the impact of the biased spatial distribution of the reward-yielding stimuli on the exploration of the shared action space. Initially, participants spontaneously selected stimuli in their respective proximal space, confirming previous experimental observations (e.g., Coello et al., 2018). Afterwards, the selection behaviour changed across the blocks of trials: Without being aware of it, participants were attracted by the area in which the probability of selecting a reward-yielding stimulus was higher. Specifically, they progressively acted more distally when the probability to select a reward-yielding stimulus was higher in the distal space, and more proximally when the probability to select a reward-yielding stimulus was higher in the proximal space. As already discussed before (Coello et al., 2018) and supported by the correlation analysis, this indicates that participants were sensitive to the probability of performing a successful action in relation to the distribution of reward-yielding stimuli, reflecting thus non-conscious learning of environmental regularities. Accordingly, these results expand the findings of previous studies on reward effect on attention (Anderson et al., 2013; Chelazzi et al., 2013; Jiang et al., 2013; Jiang et al., 2015) and ocular control (Camara et al., 2013; Hickey & Van Zoest, 2012) to object-oriented manual actions.

Another outcome of the present study was that participants invaded the space of their confederate when the probability of succeeding an action was higher in the confederate's proximal space. Such invading behaviour was not fully expected. Indeed, it was not observed in our previous study (Coello et al., 2018), where the probability to select a reward-yielding stimulus was equally spread across the whole action space. This observation was in line with the assumption that in a social context, for a defensive purpose, people tend to adjust the representation of their own PPS so as to avoid interfering with others' PPS (Coello & Iachini, 2016; Fujii et al., 2009; Szpak et al., 2015; Teneggi et al., 2013), except when the confederate has a passive attitude (Coello et al., 2018). Moreover, Coello et al. (2018) showed that when participants performed the stimuli-selection task alone, the behavioural adaptation leading them to act in the distal space (when associated with more reward-yielding stimuli) occurred rapidly (i.e., within the first 20 stimuli selections). In the present study, the change of strategy occurred instead following approximately 85 stimuli selections. The fact that behavioural adaptation required more action repetition indicated that the social context interfered with the optimisation of stimuli selection strategy. Specifically, the propensity to avoid others' PPS appeared here to be in conflict with the natural spatial exploration for reward search in the cooperative stimuli-selection task. As a consequence, selecting reward-yielding stimuli in the distal space was delayed when it required invading others' PPS. In the same vein, previous studies in monkeys showed that the brain regions involved in motor-related visual processing (i.e., pre-frontal and parietal cortices) adapted their response properties according to the social context: Neuronal activity depended on whether the location of two monkeys enabled them to reach for the same food item, and was also modulated by the social status of the monkeys, by discarding the stimuli near the more dominant monkey (Fujii et al., 2007; Fujii et al., 2009). This suggests that the same object can be included or not in the PPS, depending on its value and the social context.

The second important result of the present study concerns the gender difference that emerged in relation to the invasion behaviour, with males invading their confederate's space more often than females. One possible explanation could rely on the difference in arm length between males and females, the former having longer arms than the latter. However, this interpretation can be ruled out, because our analysis was based on the number of times participants acted beyond the middle of the touch-screen table, which corresponded to 25 cm, a distance that was largely within an arm's reach for both males and females. The gender effect might thus rely on other variables, such as higher order social factors. Previous research highlighted indeed differences in the regulation of social distance depending on gender (Fisher & Byrne, 1975; Iachini et al., 2016). For instance, when assessing comfortable interpersonal distance between males and females, it was found that male–male pairs prefer larger inter-personal distances than female–female pairs (Bailey et al., 1972; Iachini et al., 2016). This was supposed to be in relation with the females' tendency to be more affiliative (Uzzell & Horne, 2006) and empathic (Christov-Moore et al., 2014), and more sensitive to non-verbal behaviour (Sokolov et al., 2011), resulting in shorter interpersonal distances (**liebman1970**; Bailenson et al., 2001; Baxter, 1970; Hartnett et al., 1970).

Moreover, studies in social psychology showed that whereas females are more interpersonally oriented, males are more group-oriented (Baumeister & Sommer, 1997; Gabriel & Gardner, 1999), and engage more frequently in competitive between-group interactions than females (Pemberton et al., 1996; Vugt et al., 2007). These differences could provide a possible interpretative framework to account for the gender effect observed in the present study. We can indeed speculate that females would invade less their confederate's space because they are potentially more sensitive to PPS intrusion's consequences, which is in line with females' higher Personal Distress score obtained in the IRI scale. In contrast, males would neglect this aspect and invade other's PPS because this constitutes a more appropriate cooperative strategy to get a higher score. This is in line with males' higher prosocial tendency revealed by the SVO-Slider Measure test. Furthermore, differences were reported in previous studies concerning reward sensitivity in males and females, with females outperforming males in tasks associated with immediate compared to delayed rewards (e.g., Byrne & Worthy, 2015). This suggests that males' behaviour in the present study cannot be simply explained by a better environmental learning than females. Considering these results, it would be interesting to analyse in a further study how male and female participants would behave in a situation where dyads have to compete instead of cooperate.

Finally, a third important result concerns the change of PPS representation following the stimuli-selection task performed in a shared space. Participants for whom the probability of obtaining a reward was higher in the distal space showed an increase of their PPS representation. On the contrary, participants for whom the probability of obtaining a reward was higher in their proximal space did not show any specific change of PPS representation. This indicates that PPS representation depends not only on the body state and action system, but also on action outcomes, confirming thus previous empirical findings (Coello et al., 2012; Coello et al., 2018). Indeed, in Coello et al. (2018), participants who had a 75% chance of selecting a reward-yielding stimulus in their proximal or distal space showed instead a decrease (-2.49 cm) and increase (+2.35 cm) of PPS, respectively. An increase of PPS was also observed in a cooperation context when the distribution of reward-yielding stimuli was unbiased (+3.19 cm). In the present study, we found a broader effect of cooperation context on PPS when reward-yielding stimuli were biased towards the distal (+5.16 cm) rather than the proximal space (+1.01 cm). It is worth noting that the change of PPS was related to the amount of reward obtained and not the change in movement amplitude in the stimuli-selection task.

Taken as a whole, these results suggest that the information drawn from observing successful actions of conspecifics combined with the biased distribution of reward-yielding stimuli modulated the effect of sharing action space with confederates on PPS representation. More specifically, participants having 75% of reward-yielding stimuli located in their distal space would show a higher increase of PPS representation because the effect of the reward distribution and of sharing an action space with someone else would add up. On the contrary, for participants having 75% of reward-yielding stimuli located in their proximal space, these two effects would have combined and canceled. Thus, the decrease of PPS representation induced by the presence of more reward-yielding stimuli in the near space would have been counterbalanced by the social context. Assuming that this interpretation is correct, this would confirm that PPS representation depends on the outcome of both self-generated and observed motor actions as suggested in a previous study (Coello et al., 2018). Finally, no statistically significant difference emerged between males and females, even though they appeared to behave differently in the stimuli-selection task. Further studies could enrich these results by analysing, for instance, a situation where one participant is observing while the other is acting in a reward-biased action space.

## 5.7 CONCLUSION

In conclusion, the present study showed that (a) expected rewards in the environment in relation to motor actions combine with social interaction context; (b) these factors influence both PPS representation and exploitation, prompting people to invade others' space, and (c) this interaction would work differently between males and females. Taken as a whole, our results enrich the theoretical debate on PPS representation, providing evidence in favour of the idea that PPS representation stems from the integration of multiple factors including the agent with their physical characteristics and possibilities to act in the environment, the stimuli's value and the interaction with other individuals within a shared space. Furthermore, the findings of the present study pave the way for new research avenues in relation to gender differences in acting within PPS and adjusting its representation in social interaction contexts.

# 6

# THE EFFECT OF OTHERS' ACTION OUTCOMES ON PPS CONSTRUCTION

## 6.1 RATIONALE OF STUDY 2

The results exposed in Chapter 5 enriched the findings of Coello et al. (2018) by showing that the social context modulates the effect of action rewards on PPS representation and exploitation. Furthermore, these findings suggested also that others' action outcomes participate to the remapping of one's own PPS representation. It was speculated that this effect would be due to the integration of others' action rewards in space, observed by the individual during the execution a collaborative task.

Nevertheless, no empirical evidence has been proposed in support of such hypothesis. Indeed, despite previous findings showed that observing others' actions recruits the same sensori-motor processes implied in the execution of self-generated actions, it is still not clear to what extent observing other's actions influences PPS representation and the further selection of actions within it. The present study aimed at clarifying this issue. Specifically, the main purpose was to assess whether the combined effect of action rewards and social context (observed in Study 1) on PPS representation and exploitation was modulated by the individuals' degree of involvement in the collaborative task. For this purpose, differently from Study 1 (in which the social context consisted in a situation of co-action), the collaborative task employed in Study 2 required one participant to act and the other to observe.

More specifically, participants (observers) performed a reachability-judgment task (assessing PPS representation) before and after having observed a confederate (actors) performing a stimuli-selection task on a touch-screen table. In the stimuli-selection task, the distribution of reward-yielding stimuli could be biased or not towards either participants' proximal or distal space, as in Coello et al. (2018) and Study 1. Observers were finally required to perform at their turn the stimulus-selection task, which allowed to assess the effect of observing others' action outcomes on one's own further PPS exploitation. The distribution of reward-yielding stimuli was not biased at this moment of the task.

Two major findings emerged from Study 2: one concerning the actors' performance and one the observers' performance. The original article focused mainly on the observers' performance. In the present thesis, I focused on and discussed both the actors' and observers performances, in order to properly examine the effect of individuals involvement degree in a motor task in PPS representation and exploitation. As regards the actors' performance, results showed that when facing a passive confederate, individuals start to exploit others' PPS much later than when facing an active confederate (as shown by Study 1). Moreover, PPS representation was found to extend or remain stable, but never to constrict, not even when rewards were located in the near space. This result suggested therefore that PPS representation remaps in the presence of another individual, but that others' actions are not crucial for such a remapping to occur. As regards the observers' performances, the original result was that observing the outcomes of others' actions affects separately PPS representation and exploitation. Specifically, observing others' action rewards in space modify PPS representation, but this is not sufficient to influence PPS exploitation (i.e., the selection of actions to be performed within).

# Paying attention to the outcome of others' actions has dissociated effects on observer's peripersonal space representation and exploitation

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*Submitted work*

## 6.2 ABSTRACT

Peripersonal space representation and exploitation (i.e., the selection of motor actions within this particular space) are influenced by action outcomes and by reward prospects. The present study tested whether observing the outcomes of others' actions modulates the observer's PPS representation and exploitation. Participants (observers) performed a reachability-judgement task (assessing PPS representation) before and after having observed a confederate (actors) performing a stimuli-selection task on a touch-screen table. In the stimuli-selection task, the stimuli selected could either yield a reward or not (50%), but the probability to select a reward-yielding stimulus was biased in space, being either 50%, 25% or 75% in the actor's proximal or distal space. After the observation phase, participants performed the stimuli-selection task (assessing PPS exploitation), but with no spatial bias in the distribution of reward-yielding stimuli. Results revealed an effect of actors' actions outcome on observers' PPS representation, which changed according to the distribution of the reward-yielding stimuli in the actors' proximal and distal space. However, no significant effect of actors' action outcomes was found on observers' PPS exploitation. As a whole, the results suggest dissociated effects of observing the outcome of others' actions on PPS representation and exploitation.

## 6.3 INTRODUCTION

Performing object-directed motor actions requires to precisely represent the space where these motor actions will take place, which refers to the notion of peripersonal space (Bufacchi & Iannetti, 2018; Coello & Cartaud, 2021; de Vignemont & Iannetti, 2015; di Pellegrino & Làdavas, 2015; Rizzolatti et al., 1981). The peripersonal space (PPS hereafter) acts as an interface between the body and the environment by allowing the selection of the objects that receive particular attention in relation to intentional motor purposes (Belardinelli et al., 2018; Brozzoli et al., 2012). The particular feature of this interface is that objects located in the PPS are coded through multisensory and sensorimotor integrative processes, two mechanisms which operate in the space near single body parts (e.g., peri-hand, peri-head, peri-trunk and peri-feet PPS; Serino et al., 2015; Stone et al., 2018; Zanini et al., 2021), as well as in the space around the whole body (Noel et al., 2015a).

As highlighted by single-unit electrophysiological studies in macaque monkeys (Graziano & Gross, 1993; Rizzolatti et al., 1981), human behavioural studies (Avenanti et al., 2012; Serino et al., 2011), neuroimaging and neurophysiological studies (Makin et al., 2007; Wamain et al., 2016), and studies in brain-damaged patients (Bartolo et al., 2014; Farne et al., 2005), such mechanisms allow an enhanced multisensory treatment of nearby stimuli, which prepares the motor systems to interact with these stimuli (Belardinelli et al., 2018). Based on this sensorimotor processing, PPS representation serves two essential functions: (a) selecting potential actions towards incentive objects and (b) protecting the body from approaching hazards (Coello & Cartaud, 2021; Dosey & Meisels, 1969; Graziano & Cooke, 2006).

In order to fulfil this dual function, PPS representation constantly adjusts to the situations encountered and can thereby be modulated by several factors. First, PPS representation is highly sensitive to transient or permanent alterations of the sensorimotor system. As evidence, several studies have shown that the use of a tool can induce an extension of PPS representation (Berti & Frassinetti, 2000; Witt et al., 2005). For instance, Bourgeois et al. (2014) demonstrated that the distance at which an object is perceived to be within arm reach extended in space after tool use, providing that the tool induces a functional extension of the arm. This extension was interpreted as the consequence of the incorporation of the tool functional aspects into the users' body schema (Cardinali et al., 2021; Iriki et al., 1996; Maravita et al., 2002; Witt et al., 2005). Such incorporation would be induced by a change in body metrics across the somatosensory cortex (Cardinali et al., 2011; Cardinali et al., 2009b; Miller et al., 2019), that would result in a longer arm internal representation (Grüsser, 1983; Sposito et al., 2012).

Contrasting with the effect of tool use, damage to the sensorimotor cortex was found to impair the sensorimotor abilities on the contralateral side of the body and to induce a reduction of PPS representation, irrespectively of the body side considered (Bartolo et al., 2014). A similar reduction of the PPS representation was observed after restricting arm movements by an arm-splint for 24 hours (Toussaint et al., 2018), which is known to affect cortical excitability of the sensorimotor neurons dedicated to limb control (Avanzino et al., 2011; Facchini et al., 2002; Huber et al., 2006), resulting in reduced movement accuracy (Huber et al., 2006) and coordination (Moisello et al., 2008). In the same vein, Leclere et al. (2021) and Leclere et al. (2019) reported that changing the usual gravito-inertial force field during the performance of an object-directed motor task also produced a shrinking of PPS representation. As a whole, these findings underlined that PPS representation is highly dependent on the accuracy of inputs coming from the body and of sensori-motor internal models (Bourgeois & Coello, 2012), with the consequence that the reduction in their effectiveness generally leads to a reduction in the representation of PPS.

In addition to the factors inherent to an individual (i.e., sensorimotor representations, internal models and accuracy of body-related inputs), the valence assigned to external stimuli has also been identified to affect PPS representation. Indeed, a reduction of PPS representation was observed when potentially dangerous objects were presented within reaching distance, provided that the object's threatening part (e.g., the needle of a syringe) was directed towards participants' body (Coello et al., 2012). This result was explained by an anticipation of the potential positive/negative consequences of acting towards a dangerous object, leading to the recruitment of an approach/avoidance behavioural strategy and to a consequent adjustment of PPS representation.

In line with this view, Coello et al. (2018) went one step further by showing that the expectation of motor actions rewarding outcomes could also induce a modification of PPS representation (see also Gigliotti et al., 2021). The authors asked participants to manually select a set of visual stimuli presented on a touch-screen table. Once selected, the stimuli could either yield a reward or not. Furthermore, the distribution of reward-yielding stimuli could be equal in the whole workspace or biased towards either the distal or the proximal portion of the workspace. Results showed that, after several manual selections, participants tended to select predominantly the stimuli located in the area of the workspace associated with a higher proportion of reward-yielding stimuli, although this was entirely outside the scope of consciousness. These results extended to manual motor actions the effect previously observed on visual attention. Indeed, visual attention ws found to be preferentially oriented towards the most rewarding stimuli and conversely, deviated from stimuli associated with no reward (Akrami et al., 2018; Desimone & Duncan, 1995). Moreover, the results by Coello et al. (2018) highlighted that PPS representation seems to rely not only on the sensori-motor properties of the body, but also on reward prospects related to the motor actions performed in the environment.

Beyond the findings summarised above, recent studies addressed the issue of watching someone performing an action on the observer's PPS representation. For instance, Costantini et al. (2011) showed that PPS representation extended after observing a confederate using a tool, although only when the perceiver held a functionally and structurally similar tool. The authors concluded that PPS remapping through action observation is modulated by the observer's possibility to perform compatible actions. By contrast, Galigani et al. (2020) did not find any effect of tool-use observation on the multisensory processing of stimuli within PPS, advocating the importance of integrating sensorimotor feedback to actually induce a remapping of PPS representation. Given the divergent results of these studies, the effect of observing the outcomes of others' actions on the perceiver's PPS construction remains an open issue. More specifically, it is not known yet whether others' action outcomes remap the observer's PPS representation and PPS exploitation. We define here PPS exploitation as the participants' behaviour, and more specifically the action selection process, within their near-body action space.

Building on our previous research (Coello et al., 2018; Gigliotti et al., 2021), we investigated in the present study whether observing the outcomes of others' actions, whose goal was to find reward-yielding stimuli in a shared action space, altered the observer's PPS representation and exploitation. For that purpose, we recruited same-sex dyads of participants and asked them to perform four tasks (see Figure 6.1A). First, we assessed participants' PPS representation using a reachability-judgment task (pretest). In this task, participants were requested to estimate whether a set of visual stimuli (1 cm diameter grey dots) randomly presented across 51 distances (0 to 100 cm from the trunk) appeared reachable when imaging to stretch the right arm. Second, participants were randomly assigned the role of actor or observer. The actors were requested to perform the stimuli-selection task, which consisted in selecting with the right-index finger 12 out of 32 stimuli (2.7 cm diameter grey dots) randomly presented on a touch-screen table. Once selected, the stimuli changed their colour from grey to either red (not reward-yielding stimuli) or green (reward-yielding stimuli). The aim of the task for the actor was to find, across the blocks of trials, as many green, reward-yielding stimuli as possible.

The probability of finding a reward-yielding stimulus was manipulated so that it depended on the stimulus location on the touch-screen table (see Figure 6.1B). In the Control group, the probability to select a reward-yielding stimulus was 50% in the space near the actor (i.e., rows 1, 2 and 3 on the touch-screen table) and in the space near the observer (i.e., rows 4, 5 and 6). In the Towards Actor group, it was 75% in the space near the actor and 25% in the space near the observer. On the contrary, in the Towards Observer group, it was 75% in the space near the observer and 25% in the space near the actor. Participants performed 17 blocks of 12 stimuli selections (resulting in a total of 204 trials). Meanwhile, the observers were requested to observe the performance of the actor (observation phase), and were informed that afterwards, they would have had to perform the task themselves, contributing thus to the final score obtained by the dyad.

Third, we reassessed the PPS representation (posttest) to test whether the stimuli-selection task performed by the actors had an effect on PPS representation in both the actors and observers. Finally, we asked the observers to perform the stimuli-selection task through 17 supplementary blocks of trials (action phase), to test whether the observation of actors' performance had an impact on observers' PPS exploitation. In this last task, the probability to select a reward-yielding stimulus was 50% in the spaces near both the actor and the observer for all participants, regardless of the group assigned during the observation phase. In this way, we expected observers to base their exploration strategy on the observation of actors' performances rather than on the detection of a biased distribution of reward-yielding stimuli.

We formulated two hypotheses. First, observing the outcomes of actors' actions in the stimuli-selection task should have an effect on the observers' PPS representation. Precisely, observers should extend or reduce their PPS representation as a function of the area of the workspace associated with more reward-yielding stimuli. Second, the performances of the actors in the stimuli-selection task should have an effect on the observers' PPS exploitation. According to our rationale, when observers were to apply a stimuli selection strategy, they should select more stimuli in the space associated with the largest number of reward-yielding stimuli at the time the stimuli-selection task was performed by the actors.

## 6.4 RESULTS

The data for 78 same-sex dyads of participants ($N = 26$ in all groups) were collected and analysed. Following outliers' analysis (see Methods section for further details), 75 participants were retained for both the actors and the observers' datasets analysis. First, we analysed the actor's performance in order to confirm previous findings about the effect of biasing rewards distribution on the exploitation and representation of PPS (see Coello et al., 2018). Then, we focused on the observer's performance in order to test our research hypotheses.

### 6.4.1 *Actor performance*

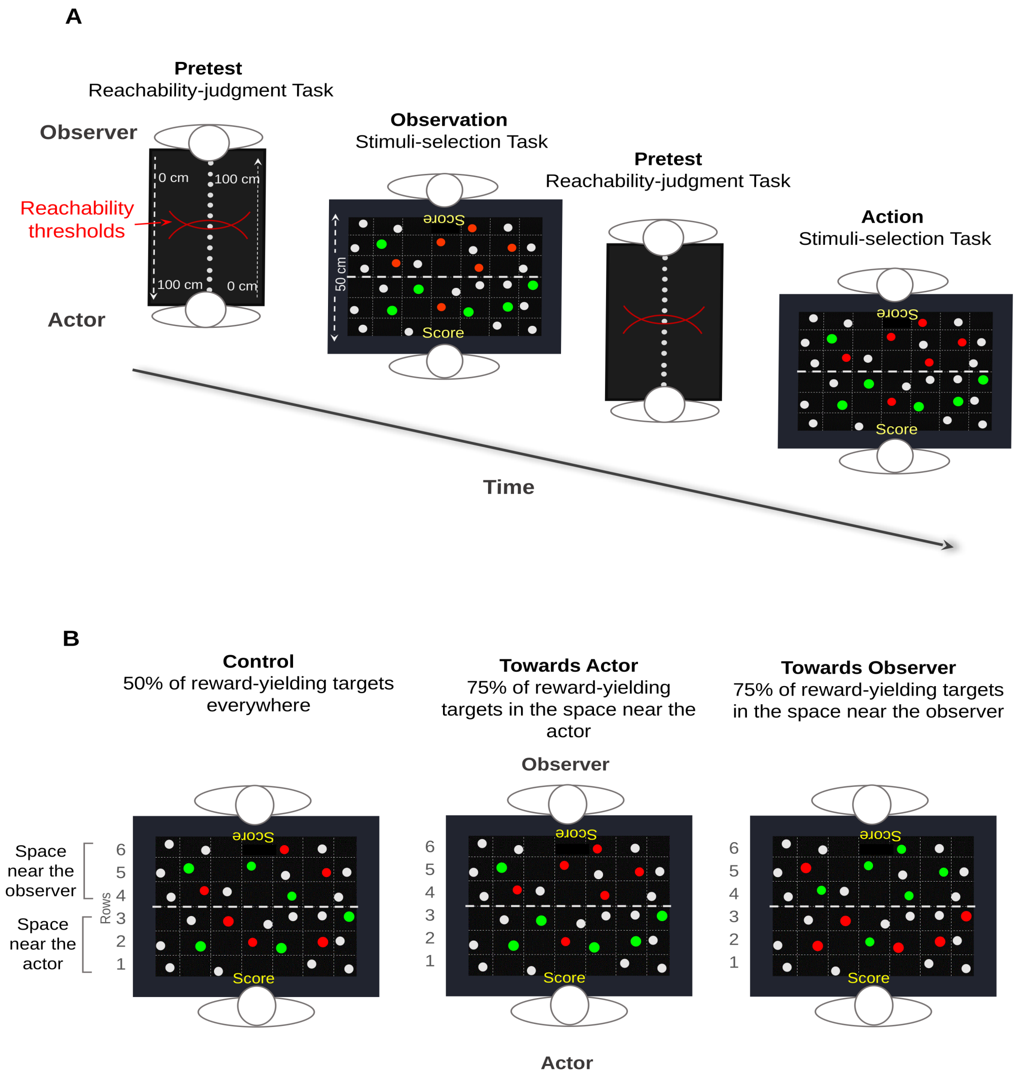
#### 6.4.1.1 *Effect of the biased distribution of reward-yielding stimuli on the actor's PPS exploitation*

As regards the stimuli-selection task, actors selected overall more stimuli in the area of the touch-screen table associated with the higher number of reward-yielding stimuli. Figure 6.2A illustrates the frequency at which each location of the touch-screen table was selected when it contained a stimulus during all the 17 blocks To analyse actors' performances in the stimuli-selection task, we pooled rows 1-2-3 to delimit the space near the actors, and rows 4-5-6 to delimit the space near the observers. As the two spaces were complementary, statistical analyses were performed only on the stimuli selected in the space near the observers, which constituted, for the actors, also an indicator of the tendency to invade others' PPS. Mean, standard deviation and 95% confidence interval values for each variable measured in the stimuli-selection task are presented in Table 6.1.

First, we assessed whether actors explored the space associated with a higher number of reward-yielding stimuli depending on the group. For this purpose, we computed, for each participant in each group, the mean number of stimuli selected across all blocks in the space near the observers (i.e., actors' distal space). The three groups were compared using a Kruskal-Wallis test with the Group (Control, Towards Actor, Towards Observer) as between-subjects factor. Statistical analysis revealed a significant effect of the Group ($H_{(2,75)} = 24.68$, $p < .001$, $\epsilon^2_H = .31$). Dunn's test for pairwise comparisons showed that the Towards Observer group selected more stimuli ($M = 6.42$, $SD = 1.97$) in the space near the observer than the Towards Actor group ($M = 3.68$, $SD = 1.73$; $Z = -4.90$, $p < .001$), but not than the Control group ($M =$

**Figure 6.1**

*Illustration of Stimuli and Tasks Order*



*Note.* A) Sequential order of the tasks. First, participants performed the reachability-judgment task. Second, the actor performed the stimuli-selection task, while the observer observed passively the confederate's performance. Third, participants realised the reachability-judgment task for a second time. Finally, participants performed again the stimuli-selection task, but switching their roles: The observer realised the stimuli-selection task, while the actor observed passively. B) Distribution of the reward-yielding stimuli as function of the group. In the Control group, the probability to select a reward-yielding stimulus was 50% in the space near the actor (rows 1, 2 and 3 of the grid) and in the space near the observer (rows 4, 5 and 6). In the Towards Actor group, the probability to select a reward-yielding stimulus was 75% in the space near the actor and 25% in the space near the observer. On the contrary, in the Towards Observer group, it was 75% in the space near the observer and 25% in the space near the actor.

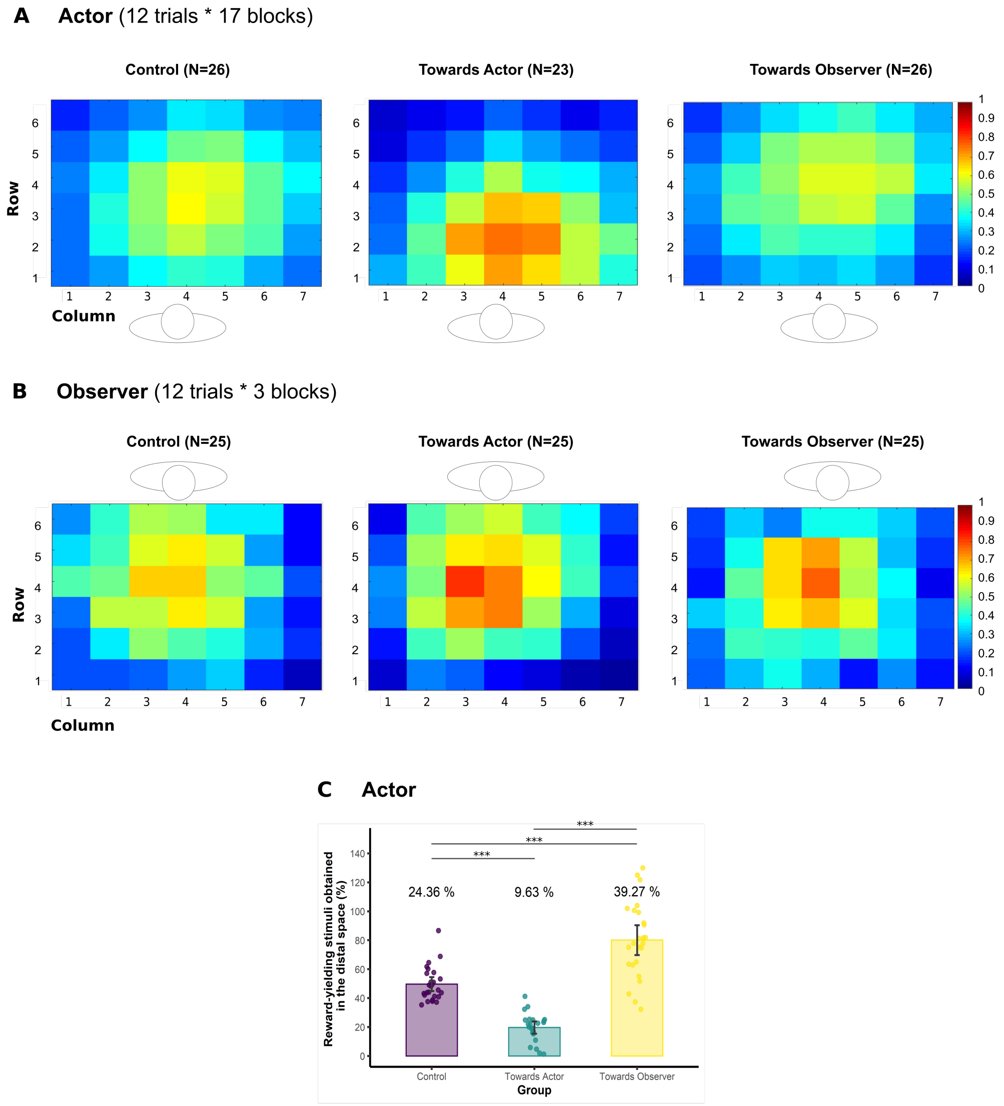
5.68, $SD$ = 1.28; $Z$ = 1.68, $p$ = .092). On its turn, the Control group selected more stimuli in the space near the observer than the Towards Actor group ($Z$ = -3.27, $p$ = .002, see Table 6.1). As a consequence, the three groups obtained a different number of reward-yielding stimuli in the space near the observer. This was confirmed by a one-way Welch's ANOVA showing a significant effect of the Group on the mean number of reward-yielding stimuli obtained in the space near the observer ($F_{(2,75)}$ = 86.04, $p$ < .001). More specifically, Games Howell post-hoc tests revealed that the Towards Observer group obtained more reward-yielding stimuli in the space near the observer ($M$ = 80.12, $SD$ = 25.49, 95% CI = [69.82, 90.41]), than both the Towards Actor group ($M$ = 19.65, $SD$ = 9.91, 95% CI = [15.37, 23.94]; $t_{(33.17)}$ = 11.18, $p$ < .001) and the Control group ($M$ = 49.69, $SD$ = 11.88, 95% CI = [44.89, 54.49]; $t_{(35.37)}$ = 5.52, $p$ < .001). On its turn, the Control group obtained more reward-yielding stimuli in the space near the observer than the Towards Actor group ($t_{(46.85)}$ = 9.65, $p$ < .001; see Figure 6.2C). These results confirmed the validity of our experimental design.

Second, we analysed how actors' exploration strategy changed at the end when compared to the beginning of the task depending on the group. For that purpose, we computed, for each participant, the difference between the mean number of stimuli selected in the space near the observer in the last 3 and first 3 blocks of stimuli selections. The three groups were compared by the means of a one-way Welch's ANOVA, with the Group (Control, Towards Actor, Towards Observer) as between-subjects factor. Results revealed a significant effect of Group ($F_{(2,75)}$ = 16.5, $p$ < .001). Wilcoxon signed-rank test for paired samples showed that the Towards Observer group selected statistically more stimuli in the space near the observer at the end compared to the beginning of the task ($Z$ = 65, $p$ = .009, $r$ = .50). By contrast, no significant change was observed for the Towards Actor group ($Z$ = 143, $p$ = .603, $r$ = .11), nor for the Control group ($Z$ = 145, $p$ = .647, $r$ = .09; see Table 6.1).

Third, we wanted to identify the precise moment at which the change in the exploration strategy occurred. For that purpose, we computed, for each participant in each group, the mean number of stimuli selected in the space near the observer in each of the 17 blocks. When considering all the 17 blocks, regression analysis revealed a progressive increase of the number of stimuli selected in the space near the observer in the Towards Observer group ($R$ = .74, $F_{(1,15)}$ = 18.21, $p$ < .001). On the contrary, no significant change in the exploration strategy was found in the Towards Actor ($R$ = .30, $F_{(1,15)}$ = 1.53, $p$ = .234) and Control groups ($R$ = .45, $F_{(1,15)}$ = 3.78, $p$ = .071; see Figure 6.3A). When looking at the precise moment at which the change in the exploration strategy became significant, permutation-based multiple comparisons revealed that the Towards Observer group's strategy started to diverge from the one of the Control group from the 14th block on (see Figure 6.3B). By contrast, no change in the exploration strategy for the Towards Actor group emerged when contrasted to the Control group, the two groups following a stable and consistent strategy all along the task (see Figure 6.3B). All mean, $Z$ and $p$ values in relation to permutation-based multiple comparisons are reported in Table 6.2.

**Figure 6.2**

*Density Maps of the Frequency at which Each Table Location was Chosen When Containing a Stimulus*



**A** **Actor** (12 trials * 17 blocks)

Control (N=26) Towards Actor (N=23) Towards Observer (N=26)

**B** **Observer** (12 trials * 3 blocks)

Control (N=25) Towards Actor (N=25) Towards Observer (N=25)

**C** **Actor**

*Note.* The rectangles represent the distribution grid composed of 42 cells (6 rows × 7 columns). The colour bar ranges from blue (rare selection) to red (frequent selection). The human silhouette above or below each density map represents participants' position during the task. A) Actor's performance during the stimuli-selection task. The Control group tended to explore the whole surface. The Towards Actor group explored mainly the space near themselves, while the Towards Observer group explored the whole surface tending slightly towards the space near the observer. B) Observer's performance during the stimuli-selection task (first 3 blocks only). The three groups did not show any particular trend in their early exploration strategy. C) Mean number of reward-yielding stimuli obtained in the distal space (near the observer) by the actor. Histograms represent the mean number of rewards-yielding targets obtained. Dots represent individual data and error bars 95% confidence intervals. Percentage values represent the proportion of rewards-yielding targets obtained in the distal space with respect to the total amount of rewards-yielding targets obtained. ***$p < .001$.

**Table 6.1**

*Means, Standard Deviations and 95% Confidence Intervals for the Stimuli-Selection Task and the Reachability-Judgment Task as a Function of the Group (Control, Towards Observer, Towards Actor) and the Role (Actor, Observer)*

| Group | *N* | Stimuli-Selection task | | | Reachability-judgment task | |
|---|---|---|---|---|---|---|
| | | All 17 Blocks | First 3 Blocks | Last 3 Blocks | Pretest | Posttest |
| | | M | *M* | *M* | *M* | *M* |
| | | SD | *SD* | *SD* | *SD* | *SD* |
| | | 95 % CI | *95 % CI* | *95 % CI* | *95 % CI* | *95 % CI* |
| *Actor* | | | | | | |
| Control | 26 | 5.68 | 5.42 | 5.68 | 0.59 cm | -0.06 cm |
| | | 1.28 | 1.84 | 1.32 | 9.35 | 9.05 |
| | | [5.16, 6.19] | [4.68, 6.16] | [5.15, 6.21] | [-3.71, 3.60] | [-3.71, 3.60] |
| Towards Actor | 23 | 3.68 | 3.87 | 3.55 | -0.64 cm | -0.88 cm |
| | | 1.73 | 2.18 | 1.90 | 0.67 | 10.95 |
| | | [2.93, 4.52] | [2.93, 4.81] | [2.73, 4.73] | [-4.83, 3.54] | [-5.62, 3.85] |
| Towards Observer | 26 | 6.42 | 5.62 | 7.31 | 1.36 cm | -4.6 cm |
| | | 1.97 | 1.93 | 2.27 | 8.89 | 9.26 |
| | | [5.62, 7.22] | [4.84, 6.39] | [6.39, 8.23] | [-2.27, 4.98] | [0.92, 8.40] |
| *Observer* | | | | | | |
| Control | 25 | 5.43 | 5.25 | 5.40 | 0.18 cm | -1.62 cm |
| | | 1.42 | 1.95 | 1.74 | 7.48 | 7.72 |
| | | [4.84, 6.01] | [4.45, 6.06] | [4.68, 6.12 ] | [-2.90, 3.27] | [-4.81, 1.56] |
| Towards Actor | 25 | 5.17 | 4.92 | 4.92 | 0.313 cm | 2.67 cm |
| | | 1.27 | 1.69 | 1.95 | 10.55 | 12.17 |
| | | [4.65, 5.69] | [4.22, 5.62] | [4.12, 5.72] | [-4.04, 4.67] | [-2.35, 7.70] |
| Towards Observer | 25 | 5.52 | 5.79 | 5.76 | 2.65 cm | 2.83 cm |
| | | 1.15 | 1.69 | 1.47 | 12.34 | 13.06 |
| | | [5.05, 6.00] | [5.09, 6.48] | [5.15, 6.37] | [-2.44, 7.74] | [-2.56, 8.22] |

*Note.* In the stimuli-selection tasks, values refer to the mean number of stimuli selected by participants. In the reachability-judgment task, values refer to the reachability threshold (cm) reported by participants. *N* indicates the number of participants in each group.

#### 6.4.1.2 *Effect of the biased distribution of reward-yielding stimuli on the actor's PPS representation*

As regards the reachability-judgment task, mean, standard deviation and 95% confidence interval values for the reachability thresholds (relative values according to arm-length) obtained in the pretest and posttest sessions for the three groups are presented in Table 6.1. In the pretest, actors' mean reachability threshold was 0.48 cm ($SD = 9.23$) on average, which corresponded to an overestimation of 0.67% of participants' mean actual arm length ($M = 71.12$ cm, $SD = 4.63$). In the pretest, the mean reachability threshold was not statistically different in the three groups (Control, Towards Actor, Towards Observer), which were thus homogeneous at the beginning of the task (Control vs. Towards Actor: $t_{(47)} = 0.45$, $p = 1.000$; Control vs. Towards Observer: $t_{(50)} = -0.30$, $p = 1.000$; Towards Observer vs. Towards Actor: $t_{(47)} = 0.75$, $p = 1.000$).

Reachability thresholds were statistically compared using a two-way Session × Group mixed ANOVA, with the Session (Pretest, Posttest) as within-subjects factor and the Group (Control, Towards Actor, Towards Observer) as between-subjects factor. Statistical analysis showed no significant effect of Group ($F_{(2,72)} = 1.12$, $p = .330$,

**Table 6.2**

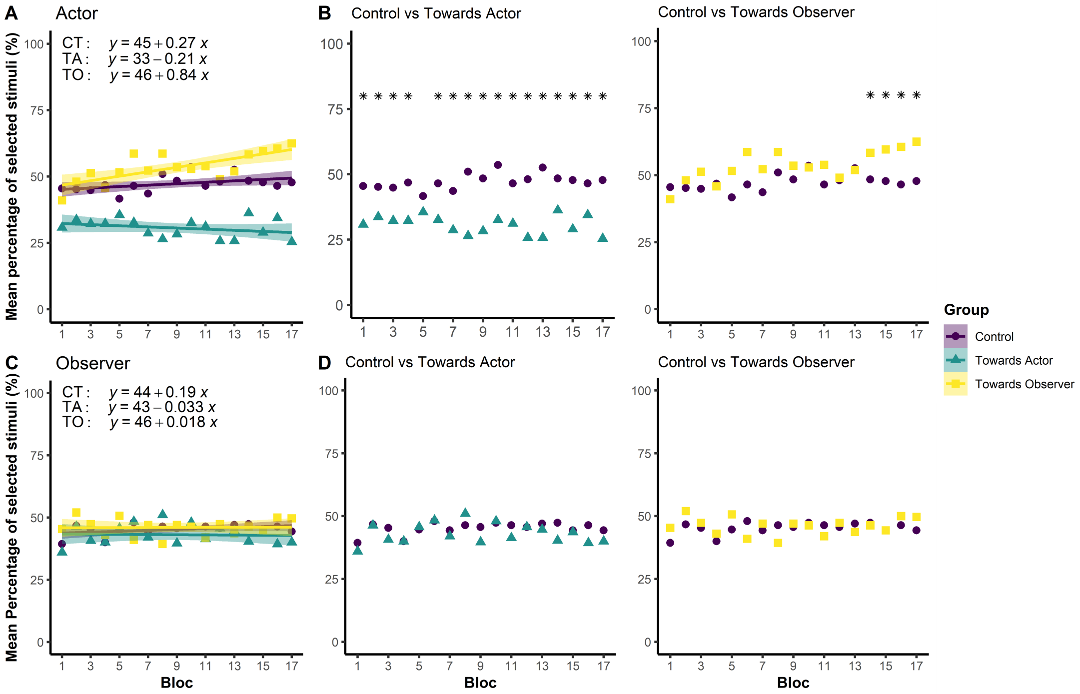
*Mean Percentage of Stimuli Selected by Each Group in the Space Near the Observer (for the Actor) and in the Space Near the Actor (for the Observer), z and p Values Returned by Permutation-Based Multiple Comparisons*

| Block | $M_{CT}$ | vs. | $M_{TA}$ | $z$ | $p$ | $M_{CT}$ | vs. | $M_{TO}$ | $z$ | $p$ |
|---|---|---|---|---|---|---|---|---|---|---|
| *Actor* | | | | | | | | | | |
| 1 | 45.51 | | 30.80 | 2.24 | .026 * | 45.51 | | 41.03 | 0.79 | .463 |
| 2 | 45.19 | | 33.70 | 2.08 | .039 * | 45.19 | | 48.08 | -0.56 | .620 |
| 3 | 44.87 | | 32.25 | 2.45 | .013 * | 44.87 | | 51.28 | -1.20 | .255 |
| 4 | 46.79 | | 32.25 | 2.28 | .021 * | 46.79 | | 45.83 | 0.16 | .917 |
| 5 | 41.67 | | 35.51 | 1.00 | .321 | 41.67 | | 51.60 | -1.61 | .119 |
| 6 | 46.47 | | 32.61 | 2.31 | .018 * | 46.47 | | 58.65 | -2.02 | .049 * |
| 7 | 43.59 | | 28.62 | 2.42 | .017 * | 43.59 | | 52.24 | -1.59 | .131 |
| 8 | 50.96 | | 26.45 | 3.49 | .000 *** | 50.96 | | 58.65 | -1.22 | .243 |
| 9 | 48.40 | | 28.26 | 3.58 | .000 *** | 48.40 | | 53.53 | -0.88 | .418 |
| 10 | 53.53 | | 32.61 | 3.34 | .000 *** | 53.53 | | 52.88 | 0.10 | .959 |
| 11 | 46.47 | | 31.16 | 2.77 | .006 ** | 46.47 | | 53.85 | -1.32 | .215 |
| 12 | 48.08 | | 25.72 | 3.35 | .001 ** | 48.08 | | 49.04 | -0.14 | .923 |
| 13 | 52.56 | | 25.72 | 4.00 | .000 *** | 52.56 | | 51.92 | 0.10 | .963 |
| 14 | 48.40 | | 36.23 | 2.23 | .027 * | 48.40 | | 58.33 | -2.09 | .039 * |
| 15 | 47.76 | | 7.15 | 3.13 | .001 ** | 47.76 | | 59.62 | -2.03 | .046 * |
| 16 | 46.47 | | 7.27 | 2.52 | .011 * | 46.47 | | 60.58 | -2.62 | .009 ** |
| 17 | 47.76 | | 7.50 | 4.03 | .000 *** | 47.76 | | 62.50 | -2.89 | .004 ** |
| *Observer* | | | | | | | | | | |
| 1 | 39.33 | | 36.00 | 0.63 | .578 | 39.33 | | 45.33 | -1.07 | .309 |
| 2 | 46.67 | | 46.33 | 0.06 | 1.000 | 46.67 | | 52.00 | -0.91 | .402 |
| 3 | 45.33 | | 40.67 | 1.04 | .339 | 45.33 | | 47.33 | -0.48 | .698 |
| 4 | 40.00 | | 40.00 | 0.00 | 1.000 | 40.00 | | 43.00 | -0.60 | .600 |
| 5 | 44.67 | | 45.67 | -0.21 | .889 | 44.67 | | 50.67 | -1.29 | .227 |
| 6 | 48.00 | | 48.33 | -0.09 | 1.000 | 48.00 | | 41.00 | 1.62 | .126 |
| 7 | 44.33 | | 42.00 | 0.40 | .740 | 44.33 | | 47.00 | -0.40 | .732 |
| 8 | 46.33 | | 51.00 | -0.87 | .429 | 46.33 | | 39.33 | 1.15 | .271 |
| 9 | 45.67 | | 39.67 | 1.32 | .221 | 45.67 | | 47.00 | -0.36 | .787 |
| 10 | 47.33 | | 48.00 | -0.15 | .942 | 47.33 | | 46.33 | 0.26 | .859 |
| 11 | 46.33 | | 41.33 | 1.02 | .350 | 46.33 | | 42.00 | 0.88 | .417 |
| 12 | 45.67 | | 45.67 | 0.00 | 1.000 | 45.67 | | 47.33 | -0.28 | .835 |
| 13 | 47.00 | | 44.67 | 0.40 | .735 | 47.00 | | 43.67 | 0.57 | .610 |
| 14 | 47.33 | | 40.33 | 1.07 | .309 | 47.33 | | 46.33 | 0.16 | .917 |
| 15 | 44.33 | | 43.67 | 0.13 | .947 | 44.33 | | 44.33 | 0.00 | 1.000 |
| 16 | 46.33 | | 39.33 | 1.03 | .334 | 46.33 | | 50.00 | -0.57 | .609 |
| 17 | 44.33 | | 40.00 | 0.77 | .478 | 44.33 | | 49.67 | -1.10 | .309 |

*Note.* $M_{CT}$: Mean percentage of stimuli selected by the Control group. $M_{TA}$: Mean percentage of stimuli selected by the Towards Actor group. $M_{TO}$: Mean percentage of stimuli selected by the Towards Observer group.

**Figure 6.3**

*Mean Percentage of Stimuli Selected in the Space Near the Observer (for the Actor) or Near the Actor (for the Observer), as Function of the Group (Control, Towards Actor, Towards Observer) and the Role (Actor, Observer)*

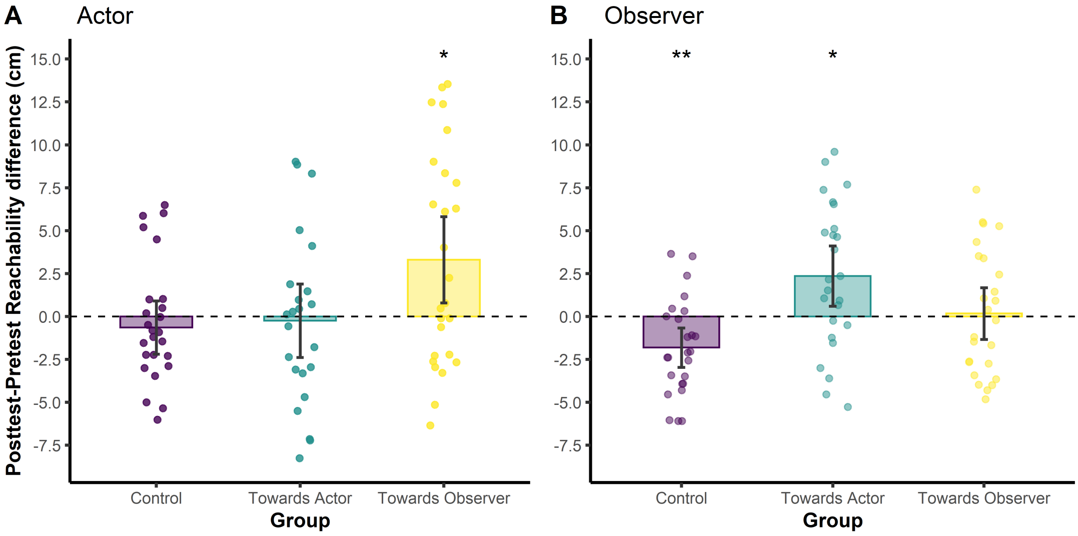


*Note.* A) Mean percentage of stimuli selected by the actor in the space near the observer across the 17 blocks, as function of the group. As shown by the linear regressions, only the Towards Observer group changed its exploration strategy during the task, selecting progressively more stimuli in the space near the observer, which was associated, for this group, to a higher probability of obtaining a reward-yielding stimulus. B) Results of the permutation-based multiple comparisons tests for the actor. The Towards Actor and Control groups showed different exploration strategies from the 1st block on, and throughout all the task. By contrast, the Towards Observer group showed a different strategy from the Control group from the 14th block on. C) Mean percentage of stimuli selected by the observer in the space near the actor across the 17 blocks, as function of the group. As shown by linear regressions, the selection strategy adopted by the three groups did not change across the task. D) Results of the permutation-based multiple comparisons for the observer. Any difference did not emerge between the three groups. $*p < .050$.

$\eta_p^2$ = .03) or Session ($F_{(1,72)}$ = 1.87, $p$ = .175, $\eta_p^2$ = .25). On the contrary, it revealed a significant Session × Group interaction ($F_{(2,72)}$ = 4.65, $SD$ = .013, $\eta_p^2$ = .11). More specifically, pairwise comparisons showed that the reachability threshold increased significantly in the posttest compared to the pretest in the Towards Observer group ($M$ = 3.31 cm, $SD$ = 6.23, 95% CI = [0.79, 5.82]; $t_{(25)}$ = 2.71, $SD$ = .012), but that it did not change neither in the Towards Actor group ($M$ = -0.24 cm, $SD$ = 4.95, 95% CI = [-2.38, 1.90], $t_{(22)}$ = -0.23, $SD$ = .818) nor in the Control group ($M$ = -0.64 cm, $SD$ = 3.84, 95% CI = [-2.19, 0.91], $t_{(25)}$ = -0.85, $SD$ = .402; see Figure 5.2A).

**Figure 6.4**

*Posttest-Pretest Difference in Reachability Threshold as Function of the Group (Control, Towards Actor, Towards Observer) and the Role (Actor, Observer)*



*Note.* A) Actor's posttest-pretest differences in reachability threshold. Only the Towards Observer group showed a significant change in reachability threshold, which increased in the posttest compared to the pretest (posttest-pretest difference > 0). No significant change was observed for the other two groups. B) Observer's posttest-pretest differences in reachability threshold. The Towards Actor Group showed a significant change in reachability threshold, which increased in the posttest compared to the pretest (posttest-pretest difference > 0). The Control group showed also a significant change in reachability threshold, which decreased in the posttest compared to the pretest (posttest-pretest difference < 0). No significant change was observed for the Towards Observer group. Histograms represent the mean posttest-pretest difference in reachability threshold. Dots represent individual posttest-pretest differences. Error bars represent 95% confidence intervals. $^*p < .050$, $^{**}p < .010$.

### 6.4.2 *Observer performance*

#### 6.4.2.1 *Effect of the biased distribution of reward-yielding stimuli on the observer's PPS representation*

As regards the reachability-judgment task, mean, standard deviation and 95% confidence interval values for the observers' reachability thresholds obtained in the pretest and posttest sessions for the three groups appear in Table 6.1. In the pretest, observers' mean reachability threshold was 1.05 cm ($SD$ = 10.20) on average, which corresponded to an overestimation of 1.46% of participants' mean actual arm length ($M$ = 71.73 cm, $SD$ = 4.63). The mean reachability threshold obtained in the pretest was not statistically different in the three groups (Control, Towards Actor, Towards Observer), which were thus homogeneous at the beginning of the task (Control vs. Towards Actor: $t_{(48)}$ = -0.05, $p$ = 1.000; Control vs. Towards Observer: $t_{(48)}$ = -0.85, $p$ = 1.000; Towards Observer vs. Towards Actor: $t_{(48)}$ = 0.72, $p$ = 1.000).

Reachability thresholds were statistically compared using a two-way Session × Group mixed ANOVA, with the Session (Pretest, Posttest) as within-subjects factor and the Group (Control, Towards Actor, Towards Observer) as between-subjects factor. Statistical analysis showed no significant effect of Group ($F_{(2,72)} = 0.68$, $p = .511$, $\eta_p^2 = .02$) or Session ($F_{(1,72)} = 3.34$, $p = .562$, $\eta_p^2 = .01$). On the contrary, it revealed a significant Session × Group interaction ($F_{(2,72)} = 8.33$, p $< .001$, $\eta_p^2 = .19$). More precisely, pairwise comparisons showed that the reachability threshold decreased significantly in the posttest compared to the pretest in the Control group ($M$ = -1.81 cm, $SD$ = 2.78, 95% CI = [-2.96, -0.66]; $t_{(24)} = -3.25$, $p = .003$), and increased significantly in the Towards Actor group ($M$ = 2.36 cm, $SD$ = 4.25, 95% CI = [0.60, 4.11]; $t_{(24)} = 2.77$, $p = .010$). No significant difference between the pretest and the posttest was observed in the Towards Observer group ($M$ = 0.18 cm, $SD$ = 3.65, 95% CI = [-1.33, 1.69]; $t_{(24)} = 0.24$, $p = .810$; see Figure 5.2B).

Taken as a whole, these results show a symmetric effect of reward-yielding stimuli on PPS representation for the actor and the observer: For both of them, reward-yielding stimuli induced an increase of PPS representation only when they were located in the distal space (i.e., in the space near the observer for the actor, and in the space near the actor for the observer).

#### 6.4.2.2 *Effect of the biased distribution of reward-yielding stimuli on the observer's PPS exploitation*

To analyse the observers' performance at the stimuli-selection task, as for the actor, we pooled rows 1-2-3 to define the space near the actor, and rows 4-5-6 to delimit the space near the observer. However, statistical analyses of the observers' performances were conducted on the stimuli selected in the space near the actor.

First, we assessed whether the observers, depending on the group, explored preferentially the space that was associated with a higher number of reward-yielding stimuli when the actor performed the task. For that purpose, we computed, for each participant in each group, the mean number of stimuli selected across all blocks in the space near the actor. The three groups were compared through a one-way ANOVA with the Group (Control, Towards Actor, Towards Observer) as between-subjects factor. Statistical analysis revealed no significant effect of the Group ($F_{(2,72)} = 0.50$, $p = .609$, $\eta_p^2 = .01$), the three groups not differing in the mean number of stimuli selected in the space near the actor (5.37 stimuli per block on average; see Table 6.1).

Second, we tested whether the observers, depending on the group, changed their exploration strategy at the end compared to the beginning of the task. Therefore, we computed, for each participant, the difference between the mean number of stimuli selected in the space near the actors in the last 3 blocks and in the first 3 blocks of trials. We compared the three groups using a two-way Session × Group mixed ANOVA, with the Block (First, Last) as within-subjects factor and the Group (Control, Towards Actor, Towards Observer) as between-subjects factor. Statistical analysis did not reveal a significant effect neither of the Group ($F_{(2,72)} = 2.03$, $p = .138$, $\eta_p^2 = .05$), nor of the Block ($F_{(1,72)} = 0.04$, $p = .851$, $\eta_p^2 = < .01$), nor of the Block × Group interaction ($F_{(2,72)} = 0.06$, $p < .937$, $\eta_p^2 = < .01$). These results were corroborated by regression analysis, which did not show any particular change in the observer's exploration strategy across the task neither in the Control group ($R = .39$, $F_{(1,15)} = 2.75$, $p = .118$), nor in the Towards Actor group ($R = .04$, $F_{(1,15)} = 0.03$, $p = .871$), nor in the Towards Observer group ($R = .03$, $F_{(1,15)} = 0.01$, $p = .921$).

Third, we compared the three groups only in the first 3 blocks, in order to test whether it was possible to find evidence for an early influence of actors' performance on the observers' exploration behaviour. Indeed, repeating the task over 17 blocks could have neutralized this effect as, for all the three groups, the probability to select a reward-yielding target was set at 50% in both the near and far space (as in the Control group). Figure 6.2B illustrates the frequency at which each location of the touch-screen table was selected when it contained a stimulus during the first 3 blocks. We conducted a one-way ANOVA on the mean number of stimuli selected in the space near the actor during the first 3 blocks, using the Group (Control, Towards Actor, Towards Observer) as between-subject factor. Again, results did not reveal any significant effect of the Group ($F_{(2,72)} = 1.51$, $p = .228$, $\eta_p^2 = .04$), ruling out the hypothesis of an early effect of actors' performance on the observers' exploration behaviour.

## 6.5 DISCUSSION

The aim of the present study was to test whether observing the outcome of others' actions influenced the observers' PPS representation and exploitation. The study was inspired by the ones by Coello et al. (2018) and Gigliotti et al. (2021), with dyads of participants performing a reachability-judgment task (to assess PPS representation) and a stimuli-selection task (to assess PPS exploitation). The novelty of the present study was that, in the stimuli-selection task, participants were assigned either the role of the actor or that of the observer. The observer was asked to perform the stimuli-selection task after observing the actor performing it.

### 6.5.1 *Actor performance*

As regards the actors' performances, results replicated previous findings about the effect of the spatial distribution of reward-yielding stimuli on both PPS representation and exploitation. Concerning actor's PPS exploitation, results showed that in the stimuli-selection task participants selected more stimuli in the space associated with a higher number of reward-yielding stimuli. Indeed, results showed that the selection strategy adopted by the Towards Actor (i.e., reward-yielding stimuli in the space near the actor) and Towards Observer groups (i.e., reward-yielding stimuli in the space far from the actor and near the observer) differed from the one adopted by the Control Group (i.e., reward-yielding stimuli randomly distributed in both spaces). As shown by plots and statistical analyses, the Towards Actor Group explored mainly its near space, by selecting, at the end of the task, 70.51% of the stimuli in this space (compared to 67.41% at the beginning of the task), for a total of 69.37% of proximal stimuli selected all along the task. Instead, at the end of the task, the Towards Observer Group selected 60.90% of stimuli in the space near the observer (i.e., in the actor's distal space; against 46.80% at the beginning of the task), for a total of 53.51% of distal stimuli selected all along the task. This effect can be explained by a statistical learning of reward-yielding stimuli location (Chelazzi et al., 2014; Jiang et al., 2013) achieved through repeated motor interactions with the workspace.

Statistical learning is associated with attentional mechanisms and it is known to alter stimulus priority within the spatial map of action space (Zelinsky & Bisley, 2015) and to guide further search behaviour (Fecteau & Munoz, 2006; Walthew & Gilchrist, 2006). However, the effect of reward distribution on the exploration strategy took place at different moments for the two groups. It was present from the first block in the Towards Actor Group, while it occurred late in the task for the Towards Observer Group (from the 14th block on). These results can be explained by the presence of a social context effect, which has already been reported in the literature (Gigliotti et al., 2021): Actors tended to split the space in two and to act predominantly in their own proximal space in order not to invade the space of the observer. As further evidence for this interpretation, we can evoke the results found by Coello et al. (2018), who observed that participants started to explore systematically more the distal space quite early in the task (from the 3rd block on) when they had to perform the task alone.

Concerning actor's PPS representation, results of the reachability-judgment task showed an extension of PPS representation when the distribution of reward-yielding stimuli was biased towards the actor's distal space, but no change when the distribution of reward-yielding stimuli was biased towards the actor' proximal space, or when it was random across both spaces. These findings are in agreement with what was reported in previous studies (Coello et al., 2018; Gigliotti et al., 2021), and corroborate the effect of reward-distribution statistical learning on PPS representation. They also confirm that the effect of rewards is modulated by the effect of the presence of another person implied in the task on PPS representation (Teneggi et al., 2013), the latter effect counterbalancing the former when rewards distribution is biased towards others' proximal space (Gigliotti et al., 2021).

### 6.5.2 *Observer performance*

As regards the observer's performances, the main finding of the present study was the presence of dissociated effects of actors' rewards on the observer's representation and exploitation of PPS. Concerning observers' PPS representation, results showed an extension of PPS representation after having observed an actor getting more rewards in their proximal space (i.e., the distal space for the observer). No significant change in PPS representation was observed after having observed an actor getting more rewards in their distal space (i.e., the proximal space of the observer). It is worth noting that these results are symmetrical with the pattern observed for the actor and can be explained in the same way; that is, by an implicit statistical learning of visual regularities (here consisting in rewards' location) altering the spatial priority map (Chelazzi et al., 2014; Fecteau & Munoz, 2006; Klink et al., 2014). In the case of the observers, statistical regularities are learnt from the outcomes of others' actions instead of their own actions. Overall, these results echo previous findings showing that the PPS representation can be altered by the observation of conspecifics' motor performances (Costantini et al., 2011).

Surprisingly, we found a constriction of PPS representation for the observers in the Control group, for whom rewards were equally distributed in distal and proximal spaces. This effect could be due to the fact that when rewards were equally distributed in space, actors explored the whole action space, which could have been experienced by the observers as a violation of their own PPS. Alternatively, in such a situation, we could have expected an increase of observers' PPS following the rewards obtained by the actor across the whole action space. Such a result was indeed observed by Coello et al. (2018), where both participants actively performed the task. Nevertheless, since we observed a reduction instead of an increase, we might conclude that when the individual is passively involved in a motor task, protecting oneself from social invasion becomes a prominent factor bypassing the effect of others' rewards. Taken as a whole, the present findings suggest that others' rewards spatial distribution can be taken into account to adjust one's own PPS representation, but that the implications of a co-action versus a cooperative social context must be more thoroughly studied in future researches in order to precisely disentangle their respective impact.

Finally, the other important result of the present study was the non-significant effect of actors' action outcomes on the observers' exploration strategy, and thus, PPS exploitation. A potential explanation for this non-significant effect could be that some participants switched their viewing perspective (Iachini & Ruggiero, 2021). That is to say, if reward-yielding stimuli were mainly situated in the proximal space of the actor, participants could have thought that, symmetrically, rewards were located in the space near themselves.

However, if this argument was correct, we should have observed, on the one hand, a different within-group variability in the Towards Actor and Towards Observer groups compared to the Control group. On the other hand, we should have observed no effect on PPS representation. Yet, this was not the case. Therefore, this indicates that this explanation can be ruled out. A second explanation could be related to a potential decay of the statistical learning in the observers at the moment of acting. Although no study has been conducted on the exact same paradigm as the one used in the present study, evidence from the literature does not support this explanation either. Indeed, statistical learning seems a very stable and robust mechanism which proved to last at least 30 minutes (Arciuli & Simpson, 2012) and even up to 24 hours (Kim et al., 2009). Since the delay between the observation and the performance of the stimuli-selection task was on average inferior to 15 minutes, the hypothesis of a decay of implicit learning can thus be dismissed, although the temporal aspect of this decay would have to be studied in the future.

Finally, the non-significant effect of others' action rewards on the observers' PPS exploitation could be due to the fact that, although implicit learning rewards distribution from others' actions affects the observer's attention and spatial maps of the visual workspace, motor experience is needed to fully embody this learning and its outcomes, and consistently orient the observer's exploration strategy. That is to say, we could speculate that observing others' rewarded actions would modify PPS representation (altering the perceptual priority map of space), but this effect would be insufficient to generalise to the organisation of motor experience within PPS (altering the motor priority map of space). Although the present study provide new insights into PPS construction, further studies are needed to better the relation between PPS representation and exploitation along with the factors that could influence it.

## 6.6 CONCLUSION

The present study showed that observing others' action rewards in space has a dissociated effect on the observers' PPS representation and exploitation. Action observation contributes to spatially localising reward-yielding stimuli in relation to the body, in order to build a suitable representation of one's own PPS. However, subsequent PPS exploitation, and therefore action selection, would rather require a personal motor experience of PPS space. In conclusion, observing others' rewarded actions would differently alter PPS representation (specifying the perceptual priority map of space) and PPS exploitation (specifying the motor priority map of space), a new framework that would require further empirical validations.

## 6.7 METHOD

### 6.7.1 *Participants*

156 healthy and right-handed (mean laterality quotient = .85, *SD* = .18; Oldfield, 1971) participants (age range = 18–35 years, *M* = 21.34, *SD* = 2.53; 100 females), took part in the experiment in exchange of course credits. They were recruited from the Psychology Department of the University of Lille (France), declared having no perceptual or motor troubles and had normal or corrected-to-normal visual acuity. Participants gave their consent after receiving an information letter about the experiment. The experimental protocol was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and was approved by the University of Lille Institutional Ethics Committee (Ref. Number 2019-374-S77).

### 6.7.2 *Justification of the chosen sample size*

The necessary sample size was calculated a priori using the G*Power software (3.1.9.4). For this purpose, we chose the ANOVA repeated measures, within-between interaction module, which was the most suited to our experimental design including the Session (Pretest, Posttest) as within-subjects factor and the Group (Control, Towards Actor, Towards Observer) as between-subjects factor. Cohen's $F$ desired effect size was chosen on the basis of the effect size found by Coello et al. (2018) of $\eta_p^2 = 0.20$, corresponding to a Cohen's $F = 0.50$.

First, we ran a power analysis taking into consideration a power of 80% (and $\alpha = .05$). This first analysis indicated that a sample of 15 participants per each condition would be required. However, since the present paradigm was not exactly the same as the one by Coello et al. (2018) and since we suspected weaker effects due to the situation of observation, we decided to run an additional power analysis considering a higher power of 95% ($\alpha = .05$). This second analysis indicated that a sample of 21 participants per condition would be preferable. Therefore, we decided to recruit 25 participants (i.e., 25 pairs of participants) per each condition in order to reach the minimal required sample size even after the removal of potential outliers.

### 6.7.3 *Apparatus and stimuli*

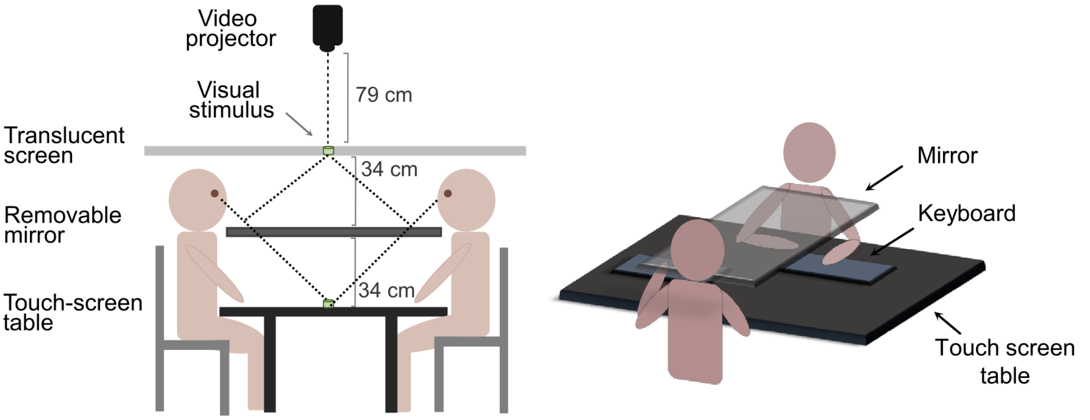
Experimental setting, paradigm and procedure were based on Coello et al., 2018 and Gigliotti et al., 2021's studies. The experimental apparatus (see Figure 6.5) consisted in a 40 touch-screen table (Samsung SUR40, 109.5 × 70.74 cm), placed in the middle of a steel structure supporting a 30 cm × 100 cm horizontal rectangular mirror and a 200 × 150 cm horizontal translucent screen. In each experimental session, two participants sat face to face on each side of the touch-screen table. They performed a reachability-judgment task and a stimuli-selection task. Depending on the task, the stimuli were displayed by the touch-screen table (stimuli-selection task) or by a video-projector (reachability-judgment task) on the mirror, which displayed the stimuli as if they were located on the touch-screen table. The tasks were implemented using MATLAB software (R2017a).

#### 6.7.3.1 *Reachability-judgment task*

In the reachability-judgment task, the stimuli consisted of 51 grey dots (1 cm diameter) on a black background projected on the mirror by the video-projector (Infocus 3926D) and through the translucent screen. Stimuli were presented one by one in a random order (inter-stimuli interval of 1.5 s), at a distance ranging between 0 and 100 cm according to the head of participants (inter-target distance of 2 cm). Accordingly, a target presented at 10 cm from the head of one participant corresponded to a target located at 90 cm from the head of the other participant. Each stimulus was displayed four times for a duration of 250 ms, providing a total of 204 trials (51 distances × 4 repetitions). During the task, the touch-screen table was covered by a black sheet in order to eliminate the effect of luminous sources on stimuli presentation. A short training session (5 trials) was performed at the beginning of the task and a short rest of 60 s was given halfway through the task. The two participants provided reachabil-

**Figure 6.5**

*Schematic Representation of the Experimental Setting*



*Note.* A) During the reachability-judgment task, the video-projector projected an image on the mirror, through a translucent screen (which improved the sharpness of the image). This generated an optical projection effect, increasing the depth of the visual field and making the stimuli appear at the level of the touch-screen table. B) Participants' posture during the reachability-judgment task. The mirror hid participants' hands and the keyboards used to provide the answers. During the task, the touch-screen table was covered by a black sheet, in order to avoid any interference from external luminous sources. Once the reachability-judgment task was completed, the mirror and the keyboards were displaced on the side, and the black sheet covering the touch-screen table removed.

ity estimates for each stimulus by pressing the left-arrow (reachable) and right-arrow (unreachable) keys of a keyboard with their left and middle fingers. Answer keys were counterbalanced across participants.

#### 6.7.3.2 *Stimuli-selection task*

In the stimuli-selection task, the stimuli consisted of 32 grey dots (2.7 cm diameter) displayed on a black background by the touch-screen table (1920 × 1080 px, active area: 88.56 × 49.81 cm). The stimuli were displayed following a non-visible distribution grid composed of 42 cells (6 rows × 7 columns; see Figure 6.1A). For each block of stimuli selections, 32 cells out of the 42 were randomly selected to contain the stimuli, which appeared at random positions according to the centre of the cell (varying from 0 to 60 pixels in the x, y directions). This allowed us to obtain a different pseudo-random stimuli configuration in each block. The task was presented as a game that had to be played together with their confederate.

The stimuli were selected by touching them one by one with the right index finger. Once selected, stimuli changed colour from grey to either red or green (both colours had 50% of chances to occur). When the stimulus became green, a sound of clinking coins was played and participants obtained one point (reward-yielding stimulus). When it became red, a buzzing sound was played and participants obtained no point (no reward-yielding stimuli). Two digital counters located on the middle of the two proximal edges of the screen displayed the total number of points obtained and updated after each stimulus selection.

Finally, following the group assignment, the probability of finding a green, reward-yielding target was manipulated so that it depended on the stimulus location on the touch-screen table (see Figure 6.1B). In the Control group, it was 50% both in the space near the actor (rows 1, 2 and 3 of the grid) and in the space near the observer (rows 4, 5 and 6). In the Towards Actor group, it was 75% in the space near the actor and 25% in the space near the observer. In reverse, in the Towards Observer group, it was 75% in the space near the observer but 25% in the space near the actor. Finally, during the whole task, the actor and the observer had no right to communicate either verbally or non-verbally.

### 6.7.4 *Procedure*

Participants were invited to sit around the table. Prior to the beginning of the experiment, the experimenter measured participants' right arm length (i.e., the distance between the acromion bone and the tip of the middle finger) and adjusted the height of their chair so that their chin was 3 cm above the edge of the mirror. Following that, participants were randomly assigned either the role of the actor or the role of the observer. The task began with a first reachability-judgment task (pretest), performed by both the actors and the observers. During this task, the stimuli were presented on the mirror placed in between participants (see Figure 5), which hid their arms from their view. The touch-screen table was covered by an opaque cloth to avoid that light sources could interfere with the execution of the task. Then, actors executed the stimuli-selection task, while observers were instructed to observe them. During this phase, the mirror was moved to the side and the black cloth covering the table was removed, so as to allow participants to see the stimuli on the touch-screen table and their arms. Next, both the actors and the observers performed a second time the reachability-judgment task (the mirror and the black cloth were put back in place). Finally, the observer executed the stimuli-selection task, while the actor remained still.

During the reachability-judgment task, the actors and the observers received the same following instructions: *"A series of luminous dots will be successively presented very briefly on the table in front of you. For each point displayed, you will have to estimate whether it seems attainable (or not) by imagining to extend your right arm, but without turning your shoulders or moving your body forward. You will have to use your left index and middle fingers to provide your answer on the keyboard. You will have to press - "Left" (or right, following the counterbalancement condition) when the luminous point seems reachable and "Right" (or left) if it does not seem reachable. Just to remind you: the points are presented for a very short delay. Therefore, try to answer as fast as possible, but trying to make as less errors as possible. Your answer should be as instinctive as possible. Finally, I ask you not to move your head (forwards or backwards) during the whole task."*

The stimuli-selection task was presented to the actors and the observers as a game that had to be played together. They received the following instructions: *"During this game, a set of stimuli will be randomly distributed on the touch-screen table in front of you. When selected, a stimulus will change its colour: if it turns green, you win 1 point, if it turns red, you win no point. When you select 12 stimuli, a new game round, that is, a new set of stimuli, will be displayed. During this game, each one of you will have a specific objective: (Instructions given to the actor): As regards you, your task will be to select 12 consecutive stimuli during each game round. Your objective will be to try to find as many green stimuli as possible. To select a stimulus, you will have to click on it by using your right index finger. You will have to use only your right arm. (Instructions given to the observer): In the meanwhile, your task will be to observe your partner's performance. At the end, it will be your turn to play: you will have the possibility to make 17 supplementary game rounds, in order obtain more points and increase the final score of the dyad. The aim of this game is to find as many green stimuli as possible, in order to obtain the highest score in collaboration with your partner! Try to beat the other dyads by achieving the highest score together! The dyad that will achieve the highest will be rewarded with a surprise prize! Be careful, there is only one rule: during the whole game, you will not be allowed to communicate, neither verbally nor by gestures. Now it is time to play!"*

### 6.7.5 *Data analysis*

#### 6.7.5.1 *Reachability-judgment task*

As regards the reachability-judgment task, we computed participants' reachability thresholds (used as a proxy of PPS representation) by applying logistic regression. We used a maximum likelihood fit procedure based on second-order derivatives (quasi-Newton method) to find the logit model that best fitted the distribution of dichotomous responses (reachable/unreachable) provided by the participant to each of the 51 stimuli distances (Bourgeois & Coello, 2012). The logit model was obtained through Equation 5.1:

$$Y = \frac{exp^{(\alpha+\beta*X)}}{1+exp^{(\alpha+\beta*X)}}$$

In the above equation, $Y$ is reachable/unreachable answer provided by the participant, $X$ the distance at which each one of the stimuli was presented, and (- $\alpha/\beta$) the inflection point of the curve, denoting the critical value of $X$ at which the transition from "reachable" to "unreachable" responses occurred. Therefore, - $\alpha/\beta$ corresponds to the reachability threshold. Individual reachability thresholds were subsequently corrected by subtracting participant's arm length to the - $\alpha/\beta$ value. Reachability thresholds were computed separately for the pretest and the posttest sessions.

#### 6.7.5.2 *Stimuli-selection task*

As regards the stimuli-selection task, we assessed participants' selection strategy (as a proxy of PPS exploitation) by computing:

1. The mean number of stimuli selected *across all blocks* in the space near the observer (when analysing actor's performance) or in the space near the actor (when analysing observer's performance), in order to assess groups' tendency to explore the space associated with higher number of reward-yielding stimuli.
2. The mean number of stimuli selected in *the first three and last three blocks* only, in the spaces near the observer or near the actor, in order to test whether the groups changed their exploration strategy during the task.
3. The mean number of stimuli selected in *each block*, in the spaces near the observer or near the actor, to identify the precise moment at which the change in exploration strategy occurred.
4. The mean number of *reward-yielding stimuli* obtained in the spaces near the observer or near the actor, to check the validity of the experimental design.

### 6.7.6 *Statistical analyses*

Statistical analyses were carried out on R version 3.6.1 (R Core Team, 2019) and R Studio version 1.1.456. Prior to the main statistical analysis, we checked for the presence of outliers using the median absolute deviation (MAD) method (cut-off set at 2.75; Leys et al., 2013). Outliers' analysis was conducted only in the reachability-judgment task, as it is more sensitive to extreme values, and on the posttest-pretest difference in reachability threshold, as it is at the core of our research hypothesis. Outliers' analysis was carried out separately for the actor and the observer datasets, and separately for each group. We removed 2 outliers in the actor dataset and 2 in the observer one. Two additional participants (1 in each dataset) were also excluded, as they did not correctly execute the task, providing no exploitable responses.

All parametric one-way and two-way ANOVAs were carried out using the function anova_test. Following ANOVA, parametric simple effect tests as well as post-hoc multiple comparisons were performed using the function pairwise_t_test. In case of violation of the homoscedasticity assumption, we carried out a one-way Welch's ANOVA for independent groups using the function welch_anova_test. In this case, simple effects were tested through the Wilcoxon signed-rank test, performed with the functions wilcox_test and wilcox_effsize for effect size computation, and post-hoc multiple comparisons through the Games-Howell test, using the function games_howell_test. In case of heteroscedasticity and major violation of the normality assumption, we performed a Kruskal-Wallis test, a non-parametric equivalent of one-way ANOVA for independent groups designs, by using the functions kruskal_test and kruskal_effsize to obtain effect sizes. Post-hoc multiple comparisons were then performed by the means of the Dunn's test, using the function dunn_test. All the functions beforementioned were part of the package "rstatix" version 0.7.0 (Kassambara, 2021).

In the stimuli-selection task, the performances of the Towards Actor and the Towards Observer Groups were compared to the Control Group for each block of trials by means of permutation-based multiple comparisons (based on 9999 Monte-Carlo resampling). Comparisons were run using the independence_test function of the package "coin" version 1.4-2 (Hothorn et al., 2008). Being a resampling technique, permutation-based multiple comparisons allow the control for Type-I error and for the occurrence of false positives (Camargo et al., 2008). Therefore, no correction of $p$-values was applied as it was not needed.

For parametric tests, the normality assumption was assessed by checking Q-Q plots, the homoscedasticity with the Levene's test, the homogeneity of the variance-covariance matrix with the Box's $M$ test, and the sphericity assumption with Mauchly's test. Significance threshold was set at $\alpha = .050$, except for the tests verifying the assumptions of homoscedasticity and homogeneity of the variance-covariance matrix (for which $\alpha = .100$), for the Mauchly's sphericity test (for which $\alpha = .001$) and for the post-hoc multiple comparisons, for which "-values were adjusted using Holm's correction method.

# 7

# THE HIERARCHICAL EFFECTS OF MOTOR AND SOCIAL GOALS ON OBJECT-DIRECTED ACTIONS

## 7.1 RATIONALE OF STUDY 3

In Chapters 5 and 6, I investigated the effect of action reward prospects in space (whether they are associated with self- or other-generated motor actions) and the constraints related to the social context on PPS representation and exploitation. I showed notably that PPS representation and exploitation depends on the combination of motor- and social-related factors. In the present Chapter, I aimed at investigating in greater depth the mutual influence of these factors but focusing specifically on PPS exploitation.

For this purpose, I exploited a different paradigm and adopted a motion capture technique to analyse the kinematic features of object-directed motor actions. Participants were required to grasp an object and displace it with either a personal (for a further personal use) or social intention (for a confederate's further use, including thereby another individual in the interaction). In addition, the object could either be placed on a small or a large target. By means of such paradigm, I was able to assess the combined effect of social intention (referred to as *social goal* in the original article) and the features of the final spatial target of the motor action (i.e., the task-related motor constraints; referred to as *motor goal* in the original article) on the execution of object-directed actions in PPS.

The kinematic analysis of participants' motor performances revealed that the deceleration time was specifically impacted by the motor goal, while the peak velocity was exclusively influenced by the social goal. Movement duration and trajectory height were instead modulated by both the motor and social goals, the effect of the social goal being attenuated by the effect of the motor goal. Taken as whole, these results suggested that motor and social factors have a combined and hierarchical effect on the execution of object-oriented actions. Specifically, the features of the final spatial target of the motor action (i.e., the task-related motor constraints) modulate the effect of social intention on action kinematics, modifying therefore the way individual exploit space during social interactions.

# The combined effects of motor and social goals on the kinematics of object-directed motor action

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*Published work*

## 7.2 ABSTRACT

Voluntary actions towards manipulable objects are usually performed with a particular motor goal (i.e., a task-specific object–target–effector interaction) and in a particular social context (i.e., who would benefit from these actions). Yet, but the mutual influence of these two constraints has not yet been properly studied. For this purpose, we asked participants to grasp an object and place it on either a small or large target in relation to Fitts' law (motor goal). This first action prepared them for a second grasp-to-place action which was performed under temporal constraints, either by the participants themselves or by a confederate (social goal). Kinematic analysis of the first preparatory grasp-to-place action showed that, while deceleration time was impacted by the motor goal, peak velocity was influenced by the social goal. Movement duration and trajectory height were modulated by both goals, the effect of the social goal being attenuated by the effect of the motor goal. Overall, these results suggest that both motor and social constraints influence the characteristics of object-oriented actions, with effects that combine in a hierarchical way.

## 7.3 INTRODUCTION

The planning and monitoring of an object-directed motor action (also referred to as transitive action) depend on the processing of various factors, related to both the object and the agent of the motor action. These include the intrinsic characteristics of the object such as its shape, size, weight or texture (Cuijpers et al., 2004; Eastough & Edwards, 2007; Fikes et al., 2015; Gentilucci, 2002; Santello & Soechting, 1998), its extrinsic features, such as its spatial location, orientation and distance from the agent's body (Gentilucci et al., 1991; Paulignan et al., 1991; Paulun et al., 2016), and the final posture of the limb used for the motor action (i.e., the end-state comfort effect; Rosenbaum et al., 1992). These factors influence various features of the ongoing motor action, including the kinematics of the approach movement and the grasping of the object. For instance, object size and distance modulate arm velocity and aperture of the grip, and they also shape the posture of the hand and fingers on the object, thus allowing for a correct grasp (Ansuini et al., 2008; Sartori et al., 2012; Sartori et al., 2013b; Schettino et al., 2003; Weir et al., 2015).

In addition to the physical characteristics of manipulable objects, the motor goal of the action (i.e., the task-specific object–target–effector interaction) also influences the kinematic features of an object-directed motor action. This has been well documented in tasks modifying the physical characteristics of the motor target (intended as the final spatial location), such as its distance or size (Fitt's law; Fitts, 1954). In this respect, the main finding is that movement duration concurrently increases with the reduction in target size or the increase in target distance (in relation to the resulting index of difficulty; Fitts, 1954). Furthermore, the pioneering work by Marteniuk et al. (1987) revealed that what people intend to do with the object after having grasped it (e.g., grasp-to-throw or grasp-to-place) influences the kinematic pattern of the grasping action. The effect of the motor goal on the spatio-temporal features of motor performance was later confirmed in different grasping tasks (Ansuini et al., 2008; Ansuini et al., 2006; Naish et al., 2013; Sartori et al., 2011), and extended to pointing (Chary et al., 2004), writing (Orliaguet et al., 1997) and even communicative gesturing (Pennel et al., 2003; Sartori et al., 2009b). It was further shown that observing an object-directed motor action provides the means to anticipate the underlying motor goal through spatio-temporal variations in task execution, well before the action is fully completed, so that its effects can be anticipated (Méary et al., 2005; Sartori et al., 2013a).

More recently, the social goal of an object-directed motor action was also found to influence movement kinematics (for reviews see Becchio et al., 2012; Becchio et al., 2010; Egmose & Køppe, 2017; Krishnan-barman et al., 2017; Quesque & Coello, 2015). A number of studies have indeed revealed that an object-oriented motor action performed with a social goal, (i.e. intending to influence the behaviour of another person; Jacob & Jeannerod, 2005) is characterized by a slower velocity and a higher arm trajectory (Becchio et al., 2008b; Georgiou et al., 2007; Quesque et al., 2016; Quesque et al., 2013; Vesper et al., 2016). It was suggested that such spatio-temporal deviants render the movement more salient and more likely to capture the eye-gaze and attention of the confederate involved in the interaction (Ferri et al., 2011; Quesque & Coello, 2014). For instance, using a cooperative motor task, Quesque et al. (2013) reported that the spatial amplification of a grasp-to-place motor action was broader, resulting in a higher arm trajectory, when the partner's eye-level was set at a higher position. This result is in line with the key role of the gaze in the process of action understanding in social contexts (Costantini et al., 2012; De Stefani et al., 2013; Innocenti et al., 2012; Quesque et al., 2019; Scorolli et al., 2014).

Because of their social value, the spatio-temporal variations of object-directed motor actions are also thought to serve as crucial cues for an observer to identify the agent's social goal (Ansuini et al., 2014; Cavallo et al., 2016; Lewkowicz et al., 2013). The perception of such spatio-temporal deviants induced by the social context would allow an observer to prepare appropriate motor responses, thus contributing to the achievement of a shared objective (Becchio et al., 2008a; Quesque et al., 2013) and the improvement of social interactions (Meulenbroek et al., 2007; Quesque et al., 2016). However, it was found that the detection of a social goal from motor deviants also depends on the observer's cognitive social abilities (Lewkowicz et al., 2015) and is facilitated by the presence of contextual environmental cues (Stapel et al., 2012).

Despite the wealth of studies that have highlighted the key role of motor and social goals in motor performances, no study has yet examined the effect of concurrently manipulating these two independent goals in an object-directed motor task. Moreover, the way in which the social goal was manipulated in previous studies did not help to easily dissociate its contribution to motor actions from that of the motor goal. This was for example the case when the social goal consisted in grasping an object and placing it in the hand of a confederate instead of a physical container (Ansuini et al., 2008; Becchio et al., 2008b; Di Bono et al., 2017; Sartori et al., 2009a). Although using the partner's hand as a target for the motor action altered the kinematics of the placing phase of a grasp-to-place action, suggesting an influence of social intention, the effects observed in such a situation could be the result of either the social nature of the task (social goal) or the modification of the physical characteristics of the target (motor goal).

Therefore, the combined effects of motor and social goals on the kinematics of a voluntary motor action remain an open issue. In the present study, we tackled this issue by developing a paradigm for assessing the specific effects of motor and social goals on the execution of an object-directed motor action. We designed a task involving a dyad of participants, which consisted in performing two successive grasp-to-place actions. The first action (named "preparatory action") was always performed by the same participant and consisted in grasping a wooden object in order to place it on either a small or large circle used as a spatial target (motor goal), and located in the middle of the workspace. This first action prepared participants for the second action, which could be performed by either the same participant or the confederate (social goal). This second action (named "main action") consisted in grasping and placing the same wooden object on a sideway spatial target (either a small or large circle) under temporal constraint and with feedback about motor performances. Hence, we manipulated (a) the motor goal of the task by modifying the size of the target in accordance with Fitts' law15 (index of difficulty of 2 vs. 3 bits), and (b) the social goal of the task by changing the agent performing the second grasp-to-place action (main action), in accordance with the paradigm developed by Quesque et al. (2013). By combining the motor and social goals in such a way, we were able to probe their respective contribution as well as their interaction in an object-directed motor task.

For the purpose of the present study, we focused our analysis on the variation in the temporal and kinematic parameters of the preparatory action only. Indeed, the main action served mainly to create a cooperative context for the task, as well as to orient the participants' attention on this part of the task, so that they behaved

**Table 7.1**

*Mean Values (and Standard Deviations) of Each Kinematic Parameter as a Function of the Phase, the Motor Goal and and the Social Goal*

| | | Kinematic Parameter | | | |
|---|---|---|---|---|---|
| Condition | $N$ | Movement time (ms) | Percentage of deceleration time (%) | Peak wrist velocity (mm.ms$^{-1}$) | Peak wrist elevation (mm) |
| *Grasping phase* | | | | | |
| Personal-Small | 525 | 408.65 (79.67) | 49.33 (8.65) | 494.08 (97.37) | 46.64 (10.34) |
| Social-Small | 496 | 435.29 (84.09) | 49.41 (8.29) | 475.50 (102.06) | 49.56 (10.74) |
| Personal-Large | 519 | 427.24 (81.61) | 49.50 (8.10) | 488.43 (104.31) | 47.05 (10.08) |
| Social-Large | 484 | 439.32 (83.44) | 49.00 (8.63) | 473.17 (105.32) | 48.20 (9.17) |
| *Placing phase* | | | | | |
| Personal-Small | 525 | 523.44 (91.10) | 59.37 (5.55) | 702.29 (96.06) | 52.07 (12.07) |
| Social-Small | 496 | 542.43 (86.72) | 59.60 (5.44) | 675.25 (81.22) | 53.31 (12.26) |
| Personal-Large | 519 | 517.10 (92.81) | 57.60 (5.91) | 690.09 (91.84) | 52.75 (11.99) |
| Social-Large | 484 | 516.33 (87.79) | 57.81 (5.55) | 664.92 (79.99) | 52.90 (11.58) |

*Note.* $N$ indicates the number of movements in each condition.

spontaneously in the preparatory action, which was at the core of the study. More specifically, we analysed the movement duration, peak wrist velocity, percentage of time taken by the deceleration phase and peak wrist elevation (as an index of the height of the trajectory). These analyses were performed for both the object grasping and placing phases constituting the preparatory action. In line with the above-mentioned literature, our main expectations for both the grasping and placing phases were that (a) movement time as well as trajectory height should increase and movement velocity should decrease when the preparatory action fulfils a social goal; (b) movement time and deceleration phase should increase when the motor goal of the preparatory action decreases in size; (c) the effect of the social goal on motor kinematics should interact with the effect of the motor goal, but only in the placing phase.

## 7.4 RESULTS

The temporal and kinematic parameters were computed and analysed separately for the grasping and placing phases of the preparatory action. Mean values and standard deviations for each parameter are reported in Table 7.1 as a function of the experimental condition and action phase. In addition, Figure 7.1 shows mean velocity and trajectory height profiles of the preparatory action (including both the placing and the grasping phases) as a function of the experimental conditions.

### 7.4.1 *Movement time*

Concerning the grasping phase, the conditional coefficient of determination of the model (normal distribution; see Table 7.2) was .62. Statistical analysis showed no effect of Motor goal (estimate = -10.430, $SE$ = 6.14, $\chi^2_1$ = 2.88, $p$ = .089), but an

**Table 7.2**

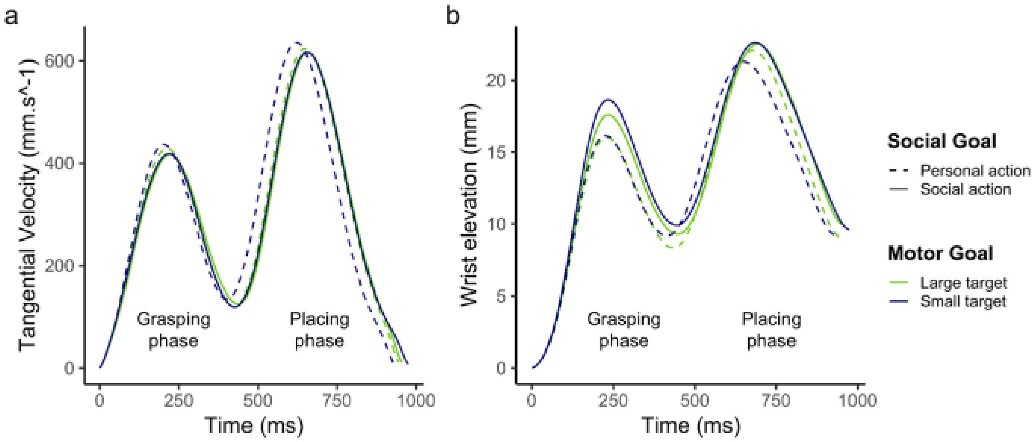
*Family Distribution, Link Function, Fixed Effects and Random Effects Specified in the Model as a Function of the Kinematic Parameter analysed*

| Kinematic parameter | Family distribution | Link function | Fixed effects | Random effects |
|---|---|---|---|---|
| *Grasping movement* | | | Social goal + Motor goal + Social goal * Motor goal | Social goal + Motor goal \| Participant |
| Movement Time | Gaussian | Identity* | | |
| Percentage of deceleration time | Gaussian | Identity* | | |
| Peak wrist velocity | Gaussian | Identity* | | |
| Peak wrist elevation | Gaussian | Log | | |
| *Placing movement* | | | | |
| Movement Time | Gaussian | Log | | |
| Percentage of deceleration time | Gaussian | Identity* | | |
| Peak wrist velocity | Gaussian | Identity* | | |
| Peak wrist elevation | Gaussian | Log | | |

*Note.* The family distribution refers to the distribution of the dependent variable. The link function consists in the mathematical function characterizing the relationship between the fixed factors and the dependent variable. The elements before and after ( | ) refer to the random slopes and random intercepts respectively. *“Glmer” function used with a Gaussian distribution and a link “identity” corresponds to a linear mixed-effects model.

**Figure 7.1**

*Mean Velocity (a) and Trajectory Height (b) Profiles as a Function of Social (Personal Action, Social Action) and Motor (Small Target, Large Target) Goals*



effect of the Social goal (estimate = -22.329, *SE* = 5.67, $\chi^2_1 = 15.48$, $p < .001$), with a longer movement time characterizing the social compared to the personal action. The Motor goal × Social goal interaction was also significant (estimate = -16.315, *SE* = 4.61, $\chi^2_1 = 12.51$, $p < .001$), with the difference in movement time between the social and personal action being greater with the small target than with the large one. Multiple comparison analysis revealed that movement time was longer for social compared to personal action when acting towards both the large (estimate = 14.20, *SE* = 6.14, *t.ratio* = 2.31, $p = .013$) and the small target (estimate = 30.50, *SE* = 6.11, *t.ratio* = 4.98, $p < .001$).

Regarding the placing phase, the conditional coefficient of determination of the model (log-normal distribution; see Table 7.2) was .02. The effect of Motor goal was significant (estimate = 0.035, *SE* = 0.01, $\chi^2_1 = 7.52$, $p = .006$), with longer movement time for the small than the large target, but the effect of Social goal was not (estimate = -0.026, *SE* = 0.01, $\chi^2_1 = 3.60$, $p = .058$). The Motor goal × Social goal interaction was significant (estimate = -0.041, *SE* = 0.01, $\chi^2_1 = 15.66$, $p < .001$), due to longer movement time for the social compared to the personal action in the presence of the small (estimate = 0.044, *SE* = 0.01, *z.ratio* = 3.12, $p < .001$) but not the large target (estimate = 0.004, *SE* = 0.01, *z.ratio* = 0.27, $p = .395$).

### 7.4.2 *Percentage of deceleration time*

Concerning the grasping phase, the conditional coefficient of determination of the model (normal distribution; see Table 7.2) was .34. The effect of Motor goal was not significant (estimate = 0.0002, *SE* = 0.005, $\chi^2_1 = 0.001$, $p = .972$), nor was the effect of the Social goal (estimate = 0.0005, *SE* = 0.005, $\chi^2_1 = 0.011$, $p = .916$). The Motor goal × Social goal interaction was not significant either (estimate = -0.005, *SE* = 0.006, $\chi^2_1 = 0.780$, $p = .377$).

As regards the placing phase, the conditional coefficient of determination of the model (normal distribution; see Table 7.2) was .30. In contrast with the grasping phase, the effect of Motor goal was significant (estimate = 0.017, *SE* = 0.004, $\chi^2_1 = 15.34$, $p < .001$), with a longer deceleration phase for actions towards the small target than towards the large one. The effect of Social goal was not significant (estimate = -0.004, *SE* = 0.003, $\chi^2_1 = 1.15$, $p = .283$), nor was the Motor goal × Social goal interaction (estimate = 0.001, *SE* = 0.004, $\chi^2_1 = 0.08$, $p = .771$).

### 7.4.3 *Peak wrist velocity*

Concerning the grasping phase, the conditional coefficient of determination of the model (normal distribution, see Table 7.2) was .67. The effect of Motor goal was not significant (estimate = 2.930, *SE* = 7.17, $\chi^2_1 = 0.17$, $p = .683$), while the effect of Social goal was (estimate = 17.437, *SE* = 6.93, $\chi^2_1 = 6.33$, $p = .012$), with the personal action being performed with a higher velocity than the social action. This effect was not modulated by the Motor goal, as the Motor goal × Social goal interaction was not significant (estimate = 4.092, *SE* = 5.30, $\chi^2_1 = 0.59$, $p = .440$).

As regards the placing phase, the conditional coefficient of determination of the model (normal distribution; see Table 7.2) was .61. As for the grasping phase, the effect of Motor goal was not significant (estimate = 10.465, *SE* = 7.55, $\chi^2_1 = 1.92$, $p = .166$), while the effect of Social goal was significant (estimate = 28.377, *SE* = 5.92, $\chi^2_1 = 22.99$, $p < .001$), with the personal action reaching a higher velocity than the social action. Again, the Motor goal × Social goal interaction was not significant (estimate = 4.093, *SE* = 5.05, $\chi^2_1 = 0.66$, $p = .417$).

### 7.4.4 *Peak wrist elevation*

Regarding the height of the trajectory during the grasping phase, the conditional coefficient of determination of the model (log-normal distribution; see Table 7.2) was .03. The effect of Motor goal was not significant (estimate = 0.010, *SE* = 0.01, $\chi^2_1$ = 0.67, $p$ = .413), while the effect of Social goal was (estimate = -0.040, *SE* = 0.006, $\chi^2_1$ = 51.13, $p < .001$), the social action being characterized by a higher trajectory than the personal action. This effect was modulated by the Motor goal, as revealed by the significant Motor goal × Social goal interaction (estimate = -0.04, *SE* = 0.01, $\chi^2_1$ = 17.76, $p < .001$). In fact, the difference in wrist elevation between the social and personal action was greater with the small target than with the large one. Multiple comparisons showed that the increased wrist elevation characterizing the social action compared to the personal action was significant with both the small target (estimate = 0.06, *SE* = 0.007, *z.ratio* = 8.22, $p < .001$) and the large one (estimate = 0.02, *SE* = 0.007, *z.ratio* = 2.603, $p$ = .005).

As regards the placing phase, the conditional coefficient of determination of the model (log-normal distribution; see Table 7.2) was .03. The effect of Motor goal was not significant (estimate = -0.003, *SE* = 0.01, $\chi^2_1$ = 0.05, $p$ = .816), nor was the effect of Social goal (estimate = -0.01, *SE* = 0.01, $\chi^2_1$ = 0.62, $p$ = .431), contrasting with the grasping phase. However, the Motor goal × Social goal interaction was significant (estimate = -0.025, *SE* = 0.009, $\chi^2_1$ = 6.89, $p$ = .009), owing to a greater difference in peak wrist elevation between the social and personal action with the small target than with the large one. Multiple comparisons showed that the increase in wrist elevation in the social action compared to personal action was significant with the small target (estimate = 0.02, *SE* = 0.01, *z.ratio* = 1.66, $p$ = .048) but not with the large one (estimate = -0.002, *SE* = 0.01, *z.ratio* = -0.18, $p$ = .572).

## 7.5 DISCUSSION

Previous studies on object-directed motor action have shown that motor performances are influenced by either the motor goal of the action (i.e., the constraints associated with the object-target-effector system) or the social goal of the action (i.e., the person who would benefit from this particular object-directed motor action; Ansuini et al., 2008; Marteniuk et al., 1987; Paulun et al., 2016; Quesque et al., 2016; Quesque et al., 2013; Weir et al., 2015). Within this context, the aim and the novelty of the present study was to examine the combined effects of motor and social goals when concurrently involved in an object-directed motor task. By analysing the temporal and kinematic features of object grasping and placing phases, we observed that motor and social goals have dissociated effects on the spatio-temporal features of object-directed motor actions, which are summarised and discussed below.

The first important finding was that the analysis of trajectory height and movement duration revealed an interaction between the effects of motor and social goals. Confirming previous reports (Becchio et al., 2008a, 2008b; Georgiou et al., 2007; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013), we found that object-directed actions performed with a social purpose were characterized by a slightly more curved path (on average 1 and 2 mm higher in the grasping and placing phases, respectively) and longer duration (on average 22 and 9 ms in the grasping and placing phases respectively) compared to object-directed actions performed with a personal purpose. However, the novel finding was that, in both the grasping and placing phases, the effect of the social goal on trajectory height and movement duration was modulated by the motor goal. More specifically, the difference in trajectory height caused by the social goal of the task was greater when the grasp-to-place action involved a small target, while it was smaller (grasping phase) or even absent (placing phase) when it involved a large target. This original result underlines that the effect of the social goal on an object-directed motor action, reported in previous studies (see Becchio et al., 2008a, 2008b; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013), depends on the constraints associated with the object–target–effector system, and therefore on the motor goal of the action.

In our study, the reduced effect of the social goal observed in the presence of the large target could be related to the low-level constraints associated with Fitts' law (Fitts, 1954). More specifically, the increase in target size induced a decrease in the index of difficulty (from 3 to 2 in our task for small and large targets, respectively), resulting in the performance of faster movements (i.e., characterized by a shorter duration). As a consequence, the faster the movement, the less time participants have to adapt the height of their arm trajectory in relation to the social goal of the task. This interference effect was particularly visible in the placing phase in which, owing to the characteristics of the experimental paradigm used, both the motor and social goals affected the motor performance. In contrast, this interference was less notable in the grasping phase, where only the social goal could directly influence the motor performance. A similar pattern of results emerged from the analysis of movement duration. Data showed that motor and social goals interacted, with a larger increase in movement duration for the social action in the presence of the small target than the large one. Again, in the presence of the large target, the difference in movement duration between the social and personal action was smaller in the grasping phase and absent in the placing phase. Taken as a whole, the interaction effects that emerged from the analysis of temporal and spatial features of the grasp-to-place action showed a modulatory effect of the motor goal on the influence of the social goal. This suggests that the features of the physical target, and more likely the constraints associated with the object–target–effector system, prevail over the social constraints of the task when both a motor and a social goals concurrently determine the spatio-temporal characteristics of the object-directed motor action.

The second important finding of the present study was the observation of differential effects of motor and social goals on the kinematic parameters of movements. Surprisingly, although the variation in movement duration was induced by both the motor and social goals, we did not observe any effect of the motor goal on the maximum velocity reached during the grasp-to-place action. As a possible explanation, we speculate that Fitts' law did not alter movement acceleration as much as the deceleration phase, for which we found an effect of target size. This observation fits well with previous studies which reported that target size mainly impacts the deceleration phase of a motor action, the latter lasting longer when the motor action is directed towards a small target (Elliott et al., 1991; Langolf et al., 1976; Mackenzie et al., 1987). By contrast, and in line with the existing literature (Becchio et al., 2008a; Georgiou et al., 2007; Quesque et al., 2013; Sartori et al., 2009b), we found an effect of the social goal on the maximum velocity, with the personal action being performed faster when compared to the social action (on average 17 and 28 mm.s$^{-1}$-1 in the grasping and placing phases, respectively).

However, when analysing the deceleration phase, we found no effect of the social goal on either the grasping or the placing phase. This absence of effect contradicts previous findings that showed that motor actions performed with a social goal are characterized by a longer deceleration phase when compared to motor actions performed with a personal goal (Ferri et al., 2011; Georgiou et al., 2007; Sartori et al., 2009b). This discrepancy between the present and previous results may stem from the combined effect of motor and social goals (when concurrently involved). In contrast to other studies, the present paradigm was conceived to dissociate the effects of motor and social goals. Thus, we tested the effect of the social goal while keeping constant the constraints associated with the object–target–effector system (i.e., using a small or a large target for either the personal or the social action). Therefore, the effect of the social goal on the deceleration phase found in previous studies could have resulted from the fact that the final motor target used to trigger the grasping action was not kept uniform across the conditions, opposing for instance the hand of a confederate to a physical support (Ansuini et al., 2008; Becchio et al., 2008b; Di Bono et al., 2017; Sartori et al., 2009a). To confirm this interpretation, future studies should replicate and extend the present findings using different paradigms based on ecological social tasks implying different kinds of movement synchronization.

## 7.6 CONCLUSION

To our knowledge, the present study represents the first experimental work investigating the combined effects of motor and social goals on the execution of object-directed motor action. The results showed that social and motor goals have an impact on specific kinematic parameters of the object-directed motor action (i.e., deceleration phase is affected only by the motor goal, while peak velocity is affected only by the social goal), as well as combined effects on other kinematic parameters (i.e., trajectory height and movement duration). More importantly, these combined effects reflect a reduction in the effect of the social goal in relation to the motor goal. These original findings suggest the existence of a hierarchy between motor and social constraints, the first taking precedence over the second. However, more investigation using different paradigms and social tasks would be required in order to confirm and extend the present findings. Furthermore, the present study suggests that the effects of motor and social goals might be sensitive to the paradigm used, and cautions against potential biases that could emerge from a lack of consideration in experimental tasks. Finally, the present findings pave the way for further research on object-directed motor actions performed in social contexts for the study of interactions, both in natural conditions and in environments involving artificial agents.

## 7.7 METHOD

### 7.7.1 *Participants*

Twenty-eight healthy participants voluntarily took part in the experiment (twenty-four females, 18–35 years old, $M = 23.36$ years, $SD = 6.60$ years). They were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971, mean laterality quotient = 0.86, $SD = 0.17$, ), and declared having normal or corrected-to-normal visual acuity and no perceptual or motor deficit. They had no prior information about the hypotheses tested in the study and gave their written informed consent prior to the beginning of the experiment. The protocol was approved by the ethical committee in behavioural sciences of the University of Lille (Ref. Number 2019–363-S75) and was conducted in conformity with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013).

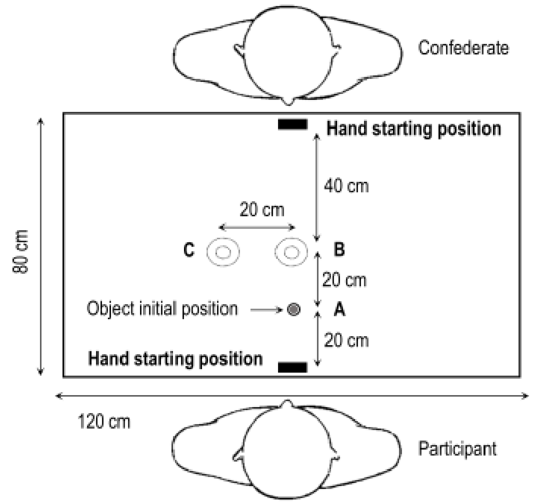
### 7.7.2 *Confederates*

Three female confederates of the experimenter (right-handed, aged 24, 25 and 27 years old) took part in the experiment, performing the task in cooperation with the participants and behaving as naive participants.

### 7.7.3 *Stimuli*

The experimental setup (see Figure 7.2) involved a 120 × 80 cm table covered by a 120 × 80 cm black, non-reflecting cloth. The task consisted in grasping and placing a wooden object (diameter 1.7 cm, thickness 1 cm) from landmark A to landmark B (preparatory action), then from landmark B to landmark C (main action). Landmarks were represented on the covering cloth by black circles. Landmark A served as the initial position for the object, while landmarks B and C served as targets for the task. The diameter of landmark A was 1.7 cm. The diameter of landmarks B and C were either 5 cm (small targets) or 10 cm (large targets). These two target sizes were chosen according to Fitts' law (Fitts, 1954), using formula:

**Figure 7.2**
*Representation of the Experimental Setup*



*Note.* The two dotted circles for targets B and C represent small and large targets.

$$ID = log_2\left(\frac{2D}{W}\right) \tag{7.1}$$

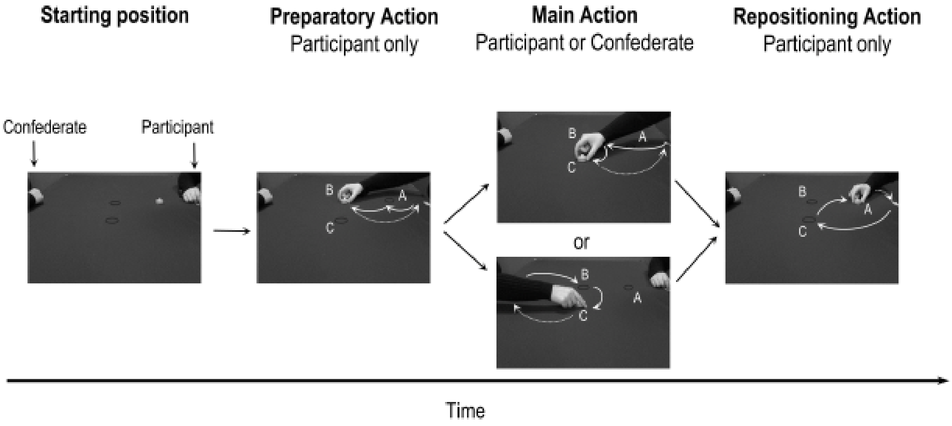
where *ID* stands for "index of difficulty" (in bits), *D* indicates the distance to the center of the target (20 cm in the present study) and *W* the width (size) of the target (5 or 10 cm of diameter in the present study). The index of difficulty was 3 bits for the small target and 2 bits for the large target. All inter-target distances were 20 cm. Small and large targets were presented using two different covering cloths, which were alternately fixed on the table. In addition to landmarks A, B and C, two white rectangular landmarks located on the opposite edges of the table were used to indicate the participant's hand starting position.

### 7.7.4 *Procedure*

The task was derived from the paradigm developed by Quesque et al. (2013). During the experiment, the participant sat on one side of the table in front of a confederate. The latter was randomly chosen between one of the three accomplices of the experimenter but pretended to be a naive participant. In order to avoid an effect of confederate's eye-level (see Quesque & Coello, 2014), the chair where the confederate sat was adjusted so that the eye-levels of confederates and participants were similar. In each trial, the participant was required to move the wooden object from one target to another following a specific sequence of three grasp-to-place actions: the *preparatory action*, the *main action* and the *repositioning action* (see Figure 7.3). The *preparatory action*

**Figure 7.3**

*Sequential Order of the Three Grasp-to-Place Motor Actions Composing the Task*



*Note.* At the end of each action (preparatory, main and repositioning), participants repositioned their hand at the starting position (dotted arrows).

was always performed by the participant and consisted in moving the wooden object from its initial position A to target B. The *main action* was presented to participants as the core action of the task; it could be performed by the participant or the confederate and involved moving the wooden object from target B to target C. We used the term *main action* as we wanted the participants to maintain their attention on this part of the task and not the preparatory action, so that the latter would be performed in a spontaneous way. Finally, the *repositioning action* was always performed by the participant, and consisted in moving the wooden object from target C to the initial position A, in order to get ready for the following trial. At the end of each action in the sequence, the participant and the confederate placed their hands in the starting position, with their thumb and index finger pinched together.

During the preparatory and the main actions, the participant was asked to place the wooden object within the circumference of the targets as precisely as possible. The error margin was established by subtracting the diameter of the wooden object from the radius of the target. As a consequence, the wooden object was considered as correctly placed when the difference between the center of the wooden object and the center of the target was not greater than 0.8 cm for the small targets and 3 cm for the large targets. During the main action only, the participant was requested to move the wooden object as fast as possible, moving the wrist at a velocity greater than 1040 mm.s$^{-1}$ when grasping the wooden object. This velocity threshold corresponded to 80 % of 1300 mm.s$^{-1}$, which was the median velocity for both the small and large targets registered in a pilot study including 10 participants.

Each grasp-to-place action was triggered by an auditory cue and the participant had 2 s to perform the required action (preparatory, main or repositioning). When the accuracy and velocity constraints were met, the participant obtained one point and a sound of clinking coins was provided. Otherwise, an error sound was emitted, indicating that no points had been obtained. The clinking coins and error sounds also triggered the repositioning action. The delays separating each action and each trial were randomized in order to prevent participants from adopting anticipatory strategies. The delay separating the end of the preparatory action and the auditory cue for the main action varied randomly between 1.5 and 2 s. The delay between the end of the main action and the auditory cue for the repositioning action was set at 2 s. The inter-trial delay varied randomly between 3 and 3.5 s.

Participants performed the task in four conditions, resulting from the combination of two experimental factors: Social goal (Personal action, Social action) and Motor goal (Small target, Large target). The Motor goal factor referred to the size (Small target, Large target) of B and C targets. The Social goal factor referred to whom the preparatory action was executed for, that is, moving the wooden object from target A to target B for a subsequent personal (Personal action) or confederate's use (Social action) in the main action. The four resulting conditions were thus: Personal-Small, Social-Small, Personal-Large and Social-Large. Each condition was performed in a separated experimental block. The order of presentation of the four blocks was pseudo-randomized: the experiment could start by either the small or the large target and by either the personal or the social action. Participants switched to the other target only once they had performed both the social and the personal actions for one target.

The experimental session started with a training phase of 10 trials (10 sequences of the three grasp-to-place actions). The main action was performed by the participant during the first five trials and by the confederate during the last five trials. Then, the experimental phase involved the above-mentioned four blocks of trials. Each block ended when participants had won 20 points, i.e., when having performed 20 correct trials satisfying both the temporal and precision constraints of the main action. To check the validity of the experimental design, we calculated the number of incorrect trials depending on the motor goal (Small target, Large target), irrespective of the social goal (Personal action, Social action). As expected and in line with Fitts' law, participants' performances were characterized by more errors with the small (378 errors) than with the large target (183 errors).

### 7.7.5 *Data recording*

Participants' motor performances were recorded using the Qualisys motion analysis system, through three Oqus infrared cameras (sampling rate 200 Hz). During each movement, the three cameras tracked the Cartesian coordinates in space ($x$, $y$, $z$) of five passive markers placed on the participant's right hand, and more specifically on the index tip, the index base, the thumb tip and the scaphoid and pisiform bones of the wrist. No markers were placed on the hand of the confederate. A sixth marker was placed on the top of the wooden object in order to analyse its position in relation to the targets and check for precision. The cameras were calibrated at the beginning of each experimental session. A calibration was considered satisfactory when the system reached a standard deviation accuracy below 0.2 mm. Finally, each time the covering cloth was changed (to switch from small to large targets and vice versa), the $x$, $y$, $z$ coordinates of the center of targets B and C were detected and calibrated, in order to obtain stable spatial references when evaluating the compliance with precision constraints.

### 7.7.6 *Data processing and statistical analysis*

Motor performances recorded by the Qualisys system were processed by an in-house script adapted from the RTMocap toolbox for Matlab (Lewkowicz & Delevoye-Turrell, 2015). In line with the existing literature (Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013), we analysed only the trajectory of the wrist marker placed at the level of the scaphoid, which expresses arm movements without including wrist rotation. Each action was composed of two phases: the grasping phase and the placing phase. Action onset was considered as the first moment when the wrist marker reached 20; Action end corresponded to the moment when the wrist marker reached 20 mm.s$^{-1}$ following peak velocity (Quesque et al., 2013). In the event that this threshold was not reached, the local minima following peak velocity was considered as the action end. For the purpose of the current study, only the parameters recorded during the preparatory action were considered. For both the grasping and the placing phases of the preparatory action, the analyses were carried out on the following kinematic parameters:

1. *Movement time (ms):* time elapsed between movement onset and movement end.
2. *Percentage of deceleration time (%)*: difference between movement time and time elapsed between movement onset and peak velocity, divided by movement time and multiplied by 100.
3. *Peak wrist velocity (mm.ms$^{-1}$)*: maximum velocity reached by wrist in grasping and placing phases.
4. *Peak wrist elevation (mm)*: trajectory height corresponding to the maximum $z$ (vertical) coordinate of wrist in grasping and placing phases.

These temporal and kinematic parameters were computed but excluded from further analysis if the movement was not correctly executed (i.e., impossibility to detect at least two local minima and/or two local maxima in the trajectory analysis), or if the reaction time was below 180 ms or above 2.5 standard deviations from the mean. Among the initial 2140 movements, 116 were removed from the data set, resulting in a loss of 5.42% of the data.

Statistical analyses and plots were performed with R version 3.5.1 (R Core Team 2018) and R Studio version 1.1.456. Each parameter of interest was analysed as a function of the Motor goal (Small target, Large target) and Social goal (Personal action, Social action) using a mixed effects model approach. Mixed effects models are used to study the effect of experimental factors (called *fixed effects parameters*) on the variable of interest, while taking into account the possible influence of other sources (referred as *random effects parameters*; e.g., inter-individual differences in sensitivity to the variables). Mixed effects models are particularly relevant for repeated measures experimental plans, as they can handle missing data and provide parameter estimates with acceptable type-I and type-II errors (Barr et al., 2013; Judd et al., 2012). In the present study, we specifically fitted each parameter dataset with a generalized linear mixed effects model, using the glmer function of the "lme 4 1.1–21" package (Bates et al., 2015b).

For each of the kinematic parameters mentioned above, we applied a model incorporating Motor goal (Small target, Large target) and Social goal (Personal action, Social action) as fixed effects, including both main effects and the interaction effect. As random effects, our model included a by-subject random intercept and by-subject random slopes for the effect of Motor and Social goals. A by-confederate random intercept was not added in the final random structure of the model, as its specification did not statistically improve the model. Therefore, such a random effects structure was chosen on the basis of a compromise between the most complete random effect structure (Barr et al., 2013) and the optimal random effect structure supported by the data (Bates et al., 2015a; Matuschek et al., 2017), in order to avoid model over-parametrization.

In addition to the fixed and random effects, glmer requires users to specify the type of error distribution. For this purpose, we analysed the distribution followed by the response variable and residuals (separately for each kinematic parameter), by computing kurtosis and skewness and visually analysing the distribution through histograms and Q-Q plots. Specifically, we fitted a Gaussian distribution to the peak wrist velocity and the percentage of deceleration time datasets for both grasping and placing phases, and to the movement time dataset for the grasping phase only. We fitted a log-normal distribution to the peak wrist elevation datasets for both grasping and placing phases, and to the movement time dataset for the placing phase only (see Table 7.2).

The model parameters (relating to fixed effects and random effects) were estimated by Laplace approximation and statistically tested with Wald's $\chi^2$. The conditional coefficient of determination $R^2$ (R_GLMM$_{(c)}^{2}$) quantifying the proportion of variance explained by the model (including both random and fixed effects; see Nakagawa et al., 2017) was calculated using the function r.squaredGLMM of the "MuMIn" package version 1.46.6 (Barton, 2019). We reported the conditional coefficient of determination $R^2$ obtained from generalized mixed models although their use and interpretation are considered controversial (Ng & Cribbie, 2017). Finally, we performed one-tailed pairwise multiple comparisons (applying a Bonferroni correction) using the functions emmeans, contrast and test of the "emmeans" package version 1.3.5.1 (Lenth et al., 2019).

# 8

# THE ROLE OF EYE GAZE IN OBJECT-DIRECTED ACTIONS

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## 8.1 RATIONALE OF STUDY 4

In Chapter 7, I showed that motor and social factors exert a combined and hierarchical effect on the execution of object-oriented actions PPS. In the present Chapter, I will explore the influence of another key factor pertaining to social interactions: the availability of eye gaze cues. Some sparse empirical evidence from previous studies highlighted that accessing other's eye gaze modulated the trajectory of object-directed actions, and that the eye-level height of a confederate induced a spatial amplification of the trajectories. Nevertheless, the exact role of eye gaze on the expression and understanding of social intention in object-directed actions was never properly assessed.

To shed light on this issue, I employed the paradigm used in Chapter 7 and previous studies (Quesque & Coello, 2014, 2015; Quesque et al., 2013). As a novelty, I applied some modifications to the paradigm in order to render the task more ecological and assess at the same time the contribution of eye gaze to the expression and the understanding of social intention through action kinematics. Specifically, participants were required to displace a dummy glass to a new position with either a personal (serve themselves some water) or a social intention (being served by a confederate). Differently from previous studies (e.g., Quesque et al., 2016), confederates' reaction to participant's action did not depend on an auditory signal, but they were required to serve only when they were able to identify the participant's social intention in the observed motor action. The task was performed while the eye gaze of the confederate was available or not to the participant.

In line with previous literature, results confirmed the presence of a social intention effect on motor performance, with actions performed with a social intention being characterised by a greater trajectory height and longer movement duration than actions performed with a personal intention. Interestingly, the difference in kinematic profile between social and personal actions was smaller when the confederates' eye gaze was not available. Furthermore, confederates' ability to identify the social intention in motor deviants was reduced when eye gaze was not available. Overall, the results showed that eye gaze cues act as a spatial attractor, modulating the way individual exploit PPS during social interaction. As a consequence, eye gaze facilitate the expression and understanding of social intentions in the kinematics of object-directed manual actions.

# The contribution of eye gaze and movement kinematics to the expression and the identification of social intention in object-directed motor actions

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*In preparation*

## 8.2 ABSTRACT

The intention to include another person into an interaction (i.e., social intention) was found to influence the spatio-temporal characteristics of motor performance. Nevertheless, the role of social cues provided by eye gaze in such a context was never properly assessed. In the present study, we tested whether limiting the access to eye gaze altered the motor-related effect of social intention on motor performances. The task was to displace manually a dummy glass to a new position in order to be virtually filled by either the participants themselves (personal intention) or a confederate facing them (social intention). The confederates performed their action only when they were able to identify the participant's social intention in the observed motor action. The task was performed while the eye gaze of the confederates was available or not, through the manipulation of an occluder. Results showed an effect of social intention on motor performance that was characterised, as previously reported, by an amplification of the kinematic spatio-temporal parameters, although to a lesser extent when the confederates' eye gaze was not available. In the latter condition, the identification of the social intention by the confederates through motor deviants was reduced. Altogether, the results revealed that the presence of eye gaze cues contributes significantly to the success of social interaction, by facilitating the expression and the understanding of social intentions in the kinematics of object-directed manual actions.

## 8.3 INTRODUCTION

During social interactions, individuals communicate their intentions and emotions through a multitude of verbal and non-verbal cues. Among the non-verbal behavioural cues, gestures, facial expressions and eye gaze participate significantly in the conveying of information at the core of the initiation and success of social interactions. As regards gestures, different classes have been identified according to the type of information they can convey. For instance, co-speech gestures (i.e., hand movements that accompany speech and which are semantically related to its content) are known to improve the quality of communication (Corballis, 2003; Dargue & Sweller, 2020; Dargue et al., 2019; Goldin-Meadow, 1999; Hostetter, 2011) and help speech comprehension in a noisy context (e.g., Drijvers & Özyüreka, 2017; Drijvers et al., 2019). Intransitive gestures (i.e. meaningful gestures that do not involve objects) can directly bring people into relationship with others (Bartolo et al., 2019; Gallagher & Frith, 2004), by automatically conveying a message (e.g., waving "Goodbye" gesture), expressing an internal state of the speaker (e.g., "I am hot" gesture) or inducing a modification of the interlocutor's behaviour (e.g., "Let's go" gesture). Finally, transitive gestures (i.e. meaningful gestures involving an object, henceforth called *object-directed actions*), have also proved to be involved in social interactions. Longly thought to be only influenced by object features (e.g., size, texture, distance; Sartori et al., 2013a; Sartori et al., 2013b) or low-level motor intentions (e.g., grasping an object to displace or to throw it; Gigliotti et al., 2020; Marteniuk et al., 1987), the execution of object-directed actions is known today to be modulated also by higher-order social intentions, that is, by the desire to include another person in the interaction (Becchio et al., 2008b; Ferri et al., 2011; Gigliotti et al., 2020; Manera et al., 2011; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013; Sartori et al., 2009a).

The modulatory effect of social intentions was initially observed through the analysis of the kinematic features of object-directed actions. More specifically, previous studies have reported that the trajectory of object-directed actions was characterized by a longer duration and higher amplitude when the action was performed with the intention to include another person in the interaction (e.g., moving an object for future use by someone else), than when it was performed with a personal intention (e.g., moving an object for future use by oneself; Becchio et al., 2008a, 2008b; Georgiou et al., 2007; Gigliotti et al., 2020; Quesque et al., 2016; Quesque et al., 2013; Vesper et al., 2016). Crucially, the perception of such action-related cues play a primary role in inferring the intentions of others (Elsner et al., 2012; Lewkowicz et al., 2013; Manera et al., 2011; Sartori et al., 2009b; Sebanz & Knoblich, 2009; Stapel et al., 2012). Indeed, it has been shown that, on the basis of these fine kinematic variations (Quesque et al., 2016) and through a perceptual anticipation process (Orliaguet et al., 1997), naive observers were able to infer the social intention associated with an object-directed motor action and to engage more rapidly into the interaction (Ansuini et al., 2008; Becchio et al., 2012; Cavallo et al., 2016; Lewkowicz et al., 2015). In light of such effects on observer's behaviour, it was suggested that the amplification of the spatial and temporal kinematic features observed in performances driven by social intention may have the function of making motor actions more communicative (Hostetter, 2011). Therefore, the kinematic variations characterising the social intention would capture the attention of the observers and provide them with cues about the actor's intention in order to respond appropriately (Gallagher, 2008; Quesque & Coello, 2014; Sartori et al., 2009a).

Besides movement cues, eye gaze constitutes another fundamental source of information in social contexts. Defined as "a window into social cognition" (Shepherd, 2010), eye gaze influences the perception and the interpretation of others' behaviour (Cook &

Smith, 1975) and participates in the regulation of social interactions (Argyle & Dean, 1965). Eye gaze cues seem privileged over other facial cues subtending social interactions, and this from a very early age (Farroni et al., 2002; Haith et al., 1977; Janik et al., 1978; Morton & Johnson, 1991). Furthermore, eye gaze contacts during face-to-face interactions are characterised by a specific temporal dynamics (Binetti et al., 2016) and used to determine speaking turns during a conversation (Ho et al., 2015). Moreover, speakers' eye gaze can be averted from or directed to the interlocutor depending on the speech content (Kendrick & Holler, 2017). Eye gaze contacts can also become more frequent when the speaker seeks approval from their interlocutor (Efran, 1968) or when the listener needs more information and further details to clarify an ambiguous point in a conversation (Macdonald & Tatler, 2013).

In the context of a physical interaction with objects, the sensitivity to others' eye gaze direction and tendency to redirect one's own gaze to the same object/location play also a crucial role in a social context (Driver IV et al., 1999; Senju & Hasegawa, 2005). Such behaviour, known as *joint attention* (Emery et al., 1997; Shaw et al., 2017), consists into a "social" coordination of attention towards a particular object, which consequently becomes a stimulus of common interest between two individuals engaging in a social interaction. Because of its attractiveness, eye contact with a confederate can interfere with the production of a motor sequence and influence its spatial trajectory (Ferri et al., 2011; Innocenti et al., 2012; Quesque & Coello, 2014; Sartori et al., 2009b; Scorolli et al., 2014). For instance, it was shown that the presence of a confederate looking at participants while performing a request gesture (i.e., opening the mouth in order to be fed), induced participants to perform slower object-directed actions, when compared to a situation of no gaze contact (Ferri et al., 2011). This interference effect was observed when the confederate looked at the participant both before (Innocenti et al., 2012) and during (Ferri et al., 2011) the execution of the movement, and even if the latter was not related to the confederate's request gesture (e.g., the confederate assuming a "give me it in the hand" while the participants performed a simple grasp-to-lift action on an object; Innocenti et al., 2012). In a similar vein, Quesque and Coello (2014) observed that the trajectory height of an object-directed action performed during a face-to-face social interaction depended on the eye-level of the confederate. More precisely, the hand path was higher when the confederate was sitting in a higher chair, independently of whether the actions were performed with a social or a personal intention. These results suggested that other's eye gaze, and in particular eye-level, was taken into account when performing motor actions in a social context, even if this was not relevant for the motor performance.

Taken as a whole, previous studies showed that non-verbal social interactions depend both on the presence of eye gaze and intention-dependent kinematic adjustment of motor actions. However, the exact interplay between the availability of eye gaze and intention-related motor adjustments in a face-to-face social interaction remains an open issue. Indeed, when raising the question of the exact role of eye gaze in the communication of social intention, two hypotheses can be envisaged. First, eye gaze might have a simple communicative role, that is eye gaze can be used directly by individuals to communicate to a confederate their intention to interact. Accordingly, when available, eye gaze would be sufficient to communicate social intention, with no need to further amplify the social-related kinematic features of object-directed actions. Eye gaze would therefore dominate over motor kinematics in the expression of social intention. Alternatively, eye gaze might have a modulatory role, that is eye gaze contributes to the expression of the social intention by emphasising its effect during the execution of object-directed actions. Accordingly, when available, eye gaze would serve as a spatial and social reference frame inducing an amplification of the effect of social intention on motor kinematics.

In order to unravel these two hypotheses, we asked participants (actors) to grasp a dummy glass from an initial position and to place it on a final position pursuing either a social intention (having some virtual water poured by a confederate) or a personal intention (pour themselves some virtual water). The task was executed in collaboration with a confederate, who had to identify the actor's intention, without talking, and to respond accordingly: To pour some virtual water when identifying a social intention or to stay still when identifying a personal intention. Actors and confederates could either have access to each other's gaze or not, through the use of a physical occluder.

We analysed the kinematic performances of the actors depending on social or personal intention subtending the performance of the motor action, and the proportion of actions whose intention was correctly identified by the confederates. Based on previous literature, we first expected that object-directed motor actions should be characterised by a higher amplitude and a longer duration when performed with a social compared to a personal intention, whatever the availability of others' eye gaze (Becchio et al., 2008b; Ferri et al., 2011; Gigliotti et al., 2020; Manera et al., 2011; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013; Sartori et al., 2009a). This corresponds indeed to a natural expression of social intention in motor actions, observed whatever the eye gaze condition. Second, we expected that the kinematic variations induced by the social and personal intentions should be either amplified or not, depending on the role played by eye gaze. More precisely, if eye gaze has a communicative role, we should observe no effect of eye gaze on the intention-induced motor deviants. On the contrary, if eye gaze has a modulatory role, we should observe an amplification of the kinematic variations induced by personal and social intentions when eye gaze is available. Concurrently with these expected effects, a higher rate of identification of the intention behind the actors' object-directed actions should be observed in the confederates, when compared to when eye gaze is not available.

## 8.4 METHOD

### 8.4.1 *Participants*

The experiment was conducted on 56 healthy participants (43 females, 18–35 years old, $M$ = 21.55 years, $SD$ = 2.49). Participants were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971, mean laterality quotient = 0.84, $SD$ = 0.20), they declared having no perceptual or motor deficits and having a normal or corrected-to-normal visual acuity. They received no information about the research hypotheses and provided their written informed consent before taking part in the experiment. The protocol was approved by the ethical committee in behavioural sciences of the University of Lille (Ref. Number 2020-437-S86) and complied with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013).

### 8.4.2 *Sample size calculation*

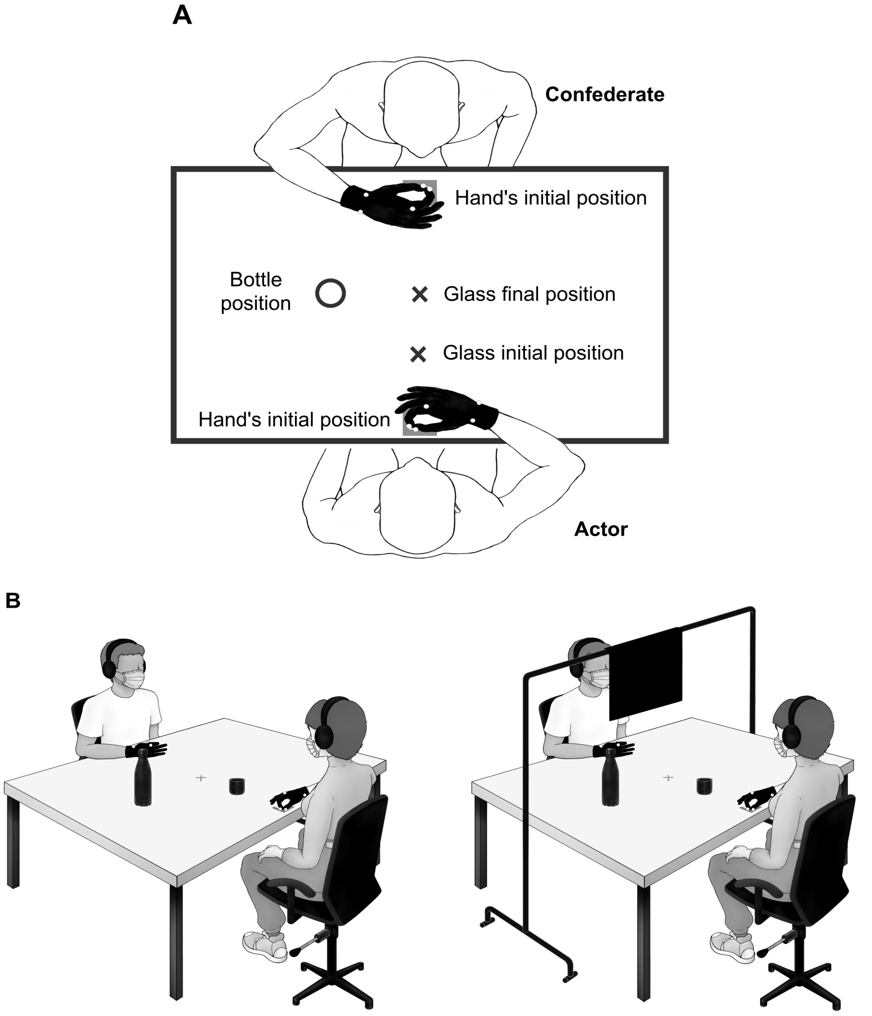
The sample size of the present study was decided on the basis of a simulation-based power analysis for mixed models (Kumle et al., 2021). Such recently proposed technique has allowed to estimate the sample size in mixed models, which is not a trivial issue. Simulation-based power analysis was carried out using the two complementary packages “mixedpower 0.1.0” (Kumle et al., 2018) and “simr 1.0.5” (Green & Macleod, 2016) on a pilot dataset of five participants and for the two main kinematic parameters of interest (peak wrist elevation and movement time of the placing phase, see Section 8.4.5). The simulation-based power analysis (1000 simulations) showed that a sample size of 25 participants performing 20 actions (trials) per condition would be sufficient to observe an interaction effect between the intention and gaze with a power $> 80\%$. Therefore we recruited 28 participants, in order to be sure to have enough data even after outliers exclusion.

### 8.4.3 *Stimuli and material*

Figure 8.1 shows a schematic illustration of the experimental setup. The task required participants to manipulate a dummy glass and a dummy bottle, made out of wood and painted with a non-reflective black paint. The glass and the bottle were placed in the space within participants’ reach, on a 120 × 100 cm table serving as workspace covered by a 120 × 100 cm black opaque cloth. The non-reflective paint and the cloth prevented the occurrence of light reflections which could interfere with the motion capture recordings. For the same reason, the experiment took place in a dark box. The task required one of the two participants (the actor) to move the glass from an initial position to a final position. Both positions were indicated by landmarks on the table (see Figure 8.1A). The task was programmed on MATLAB (version 2014a) and run on a computer Dell 7010. The computer was also equipped with the software Qualisys Track

Manager (version 2.13). Motor performances were recorded and analysed in real-time through the software interface QMT Connect for MATLAB. This interface allowed to plug Mocap data recorded by Qualisys Track Manager directly into MATLAB, which was used for online motion analysis and running the task.

**Figure 8.1**
*Schematic Illustration of the Experimental Setup*



*Note.* A) Participants sat face to face around a table (100 × 120 cm), covered by a black opaque cloth (here appearing in white for the sake of clarity and illustration). They both wore a glove endowed with five markers. The image shows the landmarks used to determine the position of the bottle, the glass and the actors' and confederates' hands. Distances: Glass initial position from glass final position= 25cm; Glass initial position from actor hand's initial position: 25cm; Glass final position from confederate hand's initial position= 50cm; Glass final position from Bottle position= 25 cm. B) Visible and Non visible gaze conditions.

### 8.4.4 *Procedure*

The task was based on the paradigm developed by Quesque et al. (2016). Participants performed the task in mixed-sex dyads and were not acquainted with each other. Throughout the experiment, participants sat around the table serving as workspace. They wore a glove endowed with reflective markers on their right hand for the kinematic analysis and a pair of headphones, used for the presentation of the auditory signals related to the task. Prior to the onset of the experiment, the height of participants' chairs was adjusted so that the participants' eyes were at the same height.

Participants of each dyad were randomly assigned either the role of "actor" or the role of "confederate". The actors' task consisted in grasping the dummy glass from an initial position and placing it on a final position, following two different intentions: Either to have some virtual water poured into the dummy glass by the confederate (social intention) or to pour themselves some virtual water into the dummy glass (personal intention). Following the actors' action, the confederates' task was either to grasp the bottle and pour some virtual water into the dummy glass or to stay still, depending on whether they perceived a social or a personal intention in the observed motor action.

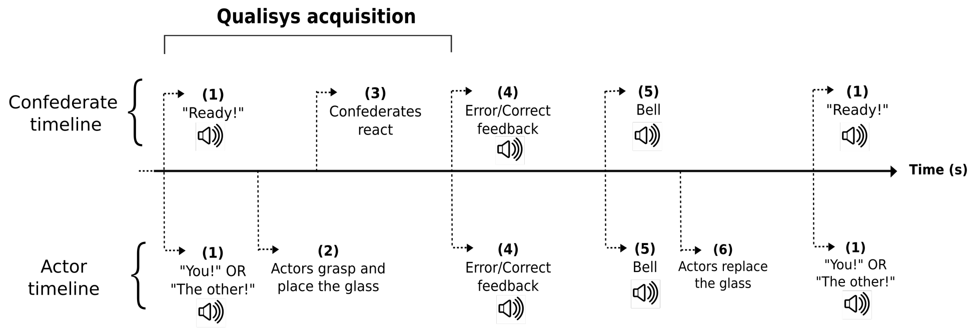
The confederates were requested to choose whether to pour some virtual water or not as soon as the actor placed the dummy glass on the final position. From that moment on, the confederate had 2 s to react before the trial was over. At the beginning of each trial, the actors received an auditory signal informing them about the intention with which they had to grasp and move the dummy glass. They could either hear the signal "You", indicating that the dummy glass had to be moved with a personal intention, or the signal "The other", indicating that the dummy glass had to be moved with a social intention. In synchrony with the actors' signal, the confederates received all the time the auditory signal "Ready". In this way, the confederates were prompted to react on the basis of the non-verbal kinematic cues extrapolated from the actors' grasp-to-place actions instead of an external auditory signal as used in previous studies (Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013). The actors and the confederates were not informed that the auditory signals received were different (see Quesque et al., 2016. Thereafter, both the actors and the confederates received an auditory feedback informing them about the success (sound of clinking coins) or not (error sound) of the trial.

A trial was considered as successful when the actors moved the dummy glass in accordance with the intention expressed in the auditory signal and the confederates reacted by producing an appropriate behavioural response. More precisely, the confederates stayed still when the actors moved the dummy glass with a personal intention and they poured the dummy glass with some virtual water when the actors moved the glass with a social intention.

Finally, a bell sound was provided, signalling the actors to grasp the dummy glass and place it back to the initial position, in order to be ready for the next trial. Figure 8.2 illustrates the temporal unfolding of a trial. At the beginning and end of each trial, the participants were requested to place their right hand, with their finger and thumb pinched together, to the hand's initial position (see Figure 8.1A). A trial did not start until the actors and confederates had positioned their hand correctly. The time elapsed between the moment participants' returned to the hand's initial position and the presentation of the next "You" / "The other" / "Ready" auditory signal corresponded to the inter-trial interval, whose duration varied randomly between 2 and 3 s.

This sequence of actions (the actors' grasp-to-place action followed by the confederates' reaction followed by the dummy glass repositioning action) corresponded to one trial (see Figure 8.2). A trial was considered as not valid and was reinitialised if a recording error occurred or if the confederate reacted after a delay of more than 2 s following the actors' grasp-to-place action. The task consisted of 2 blocks of 40 trials (20 Social intention trials and 20 Personal intention trials, presented in a random order). In one block of trials ("Visible Gaze"), participants performed the grasp-to-place action while having access to the other's face and eye gaze. In the other block of trials ("Non visible Gaze" block), a black occluder was placed in between participants, at the head level, preventing them from seeing the face and eye gaze of the other participant (see Figure 8.1B). The order of the two blocks was counterbalanced across participants. A break lasting 5 minutes occurred between the two blocks. When the face was visible, both the actors and confederates wore a face mask. The mask covered the participants' mouths in order to avoid any interference effect of the facial expression cues during the task. Throughout the experiment, participants were not allowed to verbally communicate, in order to avoid the influence of verbal cues on task performance.

**Figure 8.2**
*Temporal Unfolding of a Trial*



*Note.* (1) A trial began with the "You!" or "The other!" auditory signal being presented to actors and the "Ready!" signal to confederates. (2) Actors performed then the grasp-to-place action with either a social or a personal intention. (3) As soon as actors placed the glass to the final position, confederates had to decide whether to use the bottle to serve some virtual water or not. They disposed of a maximum delay of 2 s. (4) Following confederates' reaction, both actors' and confederate's were informed about the failure or success of the trial by means of an error/correct auditory feedback. (5) Finally, a bell sound was presented and signalled actors to grasp the glass and place it back to the initial position in order to start the following trial (1).

### 8.4.5 *Kinematic data recording and processing*

Participants' motor performances were recorded using the Qualisys motion analysis system, by means of five Oqus infrared cameras (sampling rate = 200 Hz). The five cameras tracked the 3D coordinates in space ($x$, $y$, $z$) of 10 passive markers placed on the gloves worn by the participants. The gloves worn by the actors and confederates were endowed with five markers each, which were fixed at the level of the index tip, index base, thumb tip and scaphoid and pisiform bones of the wrist. These five markers allowed to build a stable model of the hand necessary for motion recording. An 11th marker was placed on the top of the dummy glass in order to track its position in relation to the landmark on the workspace and check for precision errors. At the beginning of each experimental session, the cameras were calibrated (wand method) so that the system's standard deviation accuracy was between 0.50 and 0.99 mm.

Motor performances recorded by the Qualisys system were then analysed by an in-house script adapted from the RTMocap toolbox for Matlab (Lewkowicz & Delevoye-Turrell, 2015). In accordance with the literature (Gigliotti et al., 2020; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013), only the trajectory of the wrist marker placed at the level of the scaphoid was analysed, as it expresses arm movements without the interference of any wrist rotation. Movement onset corresponded to the first point in time at which the wrist marker reached a velocity of 20 $\mathrm{mm.s}^{-1}$. Movement end corresponded to the first time point following peak velocity at which the wrist marker velocity went below 20 $\mathrm{mm.s}^{-1}$ (Quesque et al., 2013). When this threshold was not reached, the local minima following peak velocity was considered as the action end. The grasp-to-place actions performed by the participants were composed of two phases: a grasping and a placing phase. For each phase, four kinematic parameters were computed and analysed:

- *Peak wrist elevation (mm)*: Maximum $z$ (vertical) coordinate reached by the wrist marker during a movement phase. It corresponded to the trajectory height. Peak wrist elevation values were normalised with respect to the initial wrist marker position.
- *Peak wrist velocity (mm.ms$^{-1}$)*: Maximum velocity reached by the wrist marker during a movement phase.
- *Movement time (ms)*: Time elapsed between movement phase onset and movement phase end.
- *Percentage of deceleration time (%)*: Difference between the movement time and the time elapsed between movement phase onset and peak wrist velocity, divided by the movement time and multiplied by 100.

### 8.4.6 *Statistical analysis*

Statistical analyses and plots were performed with R version 3.5.1 (R Core Team 2018) and R Studio version 1.1.456. As regards the analysis of the motor performances, each kinematic parameter was analysed separately using Linear Mixed-Effects Models. Linear Mixed-Effects Models were chosen as they allow to study the effect of experimental factors (referred as fixed-effects parameters, here corresponding to the Intention and Eye gaze) on a variable of interest (here corresponding to each kinematic parameter), while taking into account the possible influence of other sources (referred as random-effects parameters, here consisting in the inter-individual differences in the sensitivity to the type of intention or eye gaze visibility; Barr et al., 2013; Judd et al., 2012). Furthermore, mixed-effects models allow control for intra-subject variability, being thus suitable for repeated-measures experimental plans, they can handle missing data and yield parameter estimation with acceptable type-I and type-II errors (Barr et al., 2013; Judd et al., 2012). In the present study, the models used included the main effects of the factors Intention (Social, Personal) and Eye gaze (Visible, Non visible), as well as their interaction effect. The random effects structure included a by-subject random intercept and by-subject random slopes for the effect of Intention and Eye gaze (see Formula 8.1). The use of this random effects structure resulted from a compromise between the willingness to construct the most complete random effects structure and the desire to avoid model over-parameterization, by selecting the optimal random-effects structure supported by the data (Bates et al., 2015a; Matuschek et al., 2017).

$$\begin{aligned} &Kinematic\ Parameter\ of\ Interest \sim \\ &Intention + Eye\,gaze + Intention : Eye\,gaze + \\ &(1 + Intention + Eye\,gaze\ |Participant) \end{aligned} \tag{8.1}$$

Linear Mixed-Effects Models were computed and applied using the lmer function of the “lme4 1.1–23” package (Bates et al., 2015b). Model parameters were estimated using REstricted Maximum Likelihood approach (REML) and were statistically tested through $F$ test with Satterthwaite approximation for degrees of freedom (Luke, 2017) by using the function anova of the “lmerTest 3.0-1” package (Kuznetsova et al., 2017). Sum-to-zero contrasts were specified before model fitting. Normality of model residuals and homoscedasticity were verified graphically. In case of significant interaction effects, the simple effects of the variable Intention within each level of the variable Eye gaze were calculated using the function emmeans from the “emmeans 1.7.1-1” package (Lenth et al., 2019). The estimated marginal means (EMMs), summarising the model, calculated with the function emmeans are reported in the text, next to the pertinent statistical tests. ordinary marginal means (OMMs), summarising the data, are reported in Table 8.1.

As regards the analysis of the confederate’s correct identification rate of the actor’s intentions, we computed the proportion of actions in response to which the confederates reacted with an appropriate behaviour (i.e., they poured some virtual water when the actor performed the grasp-to-place action with a social intention and stayed still when the actors performed the grasp-to-place action with a personal intention). The correct identification rate computed in the Visible Eye gaze condition was statistically compared to the one computed in the Non visible Eye gaze condition by the means of a $\chi^2$ test for proportion comparison, with continuity correction, using the function prop.test of the "stats 4.1.1" package. Significant threshold was set at $\alpha = 0.05$ for all analyses.

## 8.5 RESULTS

### 8.5.1 *Analysis of actors' kinematic performances*

Grasp-to place actions were excluded from statistical analysis if they were not correctly executed (i.e., absence of two detectable local minima and/or two local maxima in the trajectory analysis) and if they resulted in outliers on at least one kinematic parameter following the absolute deviation from the median method (Leys et al., 2013). In order to keep the amount of discarded data below 5%, the threshold for outliers' rejection was set as the difference from the median +/− 4.5 times the MAD. This method led to the exclusion of 96 trials from the initial dataset of 2180 movements, resulting in 4.4% of discarded data. Mean values and standard deviations relative to the kinematic parameters analysed are reported in Table 8.1. Figure 8.3 shows the average movement time and trajectory height profiles of the grasp-to-place actions performed by the actors as a function of the Intention (Social, Personal) and the Eye gaze (Visible, Non visible).

#### 8.5.1.1 *Peak wrist elevation*

In the grasping phase, statistical analyses revealed no significant effect of Intention ($F_{(1,26.03)} = 0.35$, $p = .562$), Eye gaze ($F_{(1,26.09)} = 1.79$, $p = .192$), or the Intention × Eye gaze interaction ($F_{(1,2003.28)} = 0.16$, $p = .693$).

In the placing phase, statistical analyses revealed a significant effect of Intention ($F_{(1,27.06)} = 6.28$, $p = .018$), with actions driven by a social intention being characterised by a higher peak wrist elevation than actions driven by a personal intention (estimated mean = 23.50 mm, $SE = 2.09$ and estimated mean = 18.80 mm, $SE = 2.06$, for social and personal intention respectively; $t.ratio_{(27)} = 2.51$, $p = .018$). The effect of Eye gaze was not significant ($F_{(1,26.53)} = 0.95$, $p = .339$). However, the Intention × Eye gaze interaction was significant ($F_{(1,1999.86)} = 5.59$, $p = .018$), indicating that the effect of Intention was modulated by Eye gaze. More specifically, simple effects analyses showed that peak wrist elevation was significantly higher for actions driven by a social than personal intention in both eye gaze conditions, but the difference was larger when the eye gaze was visible (estimated mean = 5.50 mm, $SE = 1.90$, $t.ratio_{(28.8)} = 2.89$, $p = .007$) when compared to when it was not visible (estimated mean = 3.90 mm, $SE = 1.90$, $t.ratio_{(28.8)} = 2.05$, $p = .049$; see Figure 8.3).

#### 8.5.1.2 *Peak wrist velocity*

In the grasping phase, statistical analyses revealed no significant effect of Intention ($F_{(1,26.71)}$ = 0.31, $p$ = .583), but a significant effect of Eye gaze ($F_{(1,26.68)}$ = 9.67, $p$ = .004), the actions being characterised by a lower peak wrist velocity when the eye gaze was visible (estimated mean = 497 $mm.s^{-1}$, *SE* = 14.70) when compared to when it was not visible (estimated mean = 469 , *SE* = 11.90, $t.ratio_{(26.9)}$ = -3.11, $p$ = .004). The Intention × Eye gaze interaction was not significant ($F_{(1,2002.48)}$ = 0.76, $p$ = .382).

In the placing phase, statistical analyses revealed no significant effect of Intention ($F_{(1,26.79)}$= 2.02, $p$ = .167), Eye gaze ($F_{(1,27.28)}$ = 2.48, $p$ = .127), or the Intention × Eye gaze interaction ($F_{(1,2001.53)}$ = 1.18, $p$ = .278).

#### 8.5.1.3 *Percentage of deceleration time*

In the grasping phase, statistical analyses revealed a significant effect of Intention ($F_{(1,26.12)}$ = 11.45, $p$ = .002), with actions driven by a social intention being characterised by a longer deceleration period than actions driven by a personal intention (estimated mean = 53.10 %, *SE* = 1.20 and estimated mean = 51.20 %, *SE* = 1.13 for social and personal intention respectively, $t.ratio_{(26.7)}$ = 3.38, $p$ = .002). The effect of Eye gaze ($F_{(1,26.70)}$ = 0.17, $p$ = .686) and the Intention × Eye gaze interaction ($F_{(1,2007.21)}$ = 0.01, $p$ = .936) were both not significant.

In the placing phase, statistical analyses revealed a significant effect of Intention ($F_{(1,27.20)}$ = 29.37, $p$ < .001), with actions driven by a social intention being characterised by a longer deceleration period than actions driven by a personal intention (estimated mean = 64.20 %, *SE* = 0.59 and estimated mean = 62.0 %, *SE* = 0.52 for social and personal intention respectively, $t.ratio_{(26.6)}$ = 5.41, $p$ < .001). They also revealed a significant effect of Eye gaze ($F_{(1,26.9)}$= 18.27, $p$ < .001), the actions being characterised by a longer deceleration period when the gaze was visible (estimated mean = 63.80 %, *SE* = 0.58) compared to when it was not visible (estimated mean = 62.4 %, *SE* = 0.50, $t.ratio_{(26.4)}$ = -4.27, $p$ < .001). The Intention × Eye gaze interaction was not significant ($F_{(1,2008.40)}$ = 1.61, $p$ = .204).

#### 8.5.1.4 *Movement time*

In the grasping phase, statistical analyses revealed no significant effect of Intention ($F_{(1,23.82)}$ = 0.27, $p$ = .607), Gaze ($F_{(1,27.38)}$ = 3.86, $p$ = .060, or the Intention × Eye gaze interaction ($F_{(1,1999.05)}$ = 0.002, $p$ = .966).

In the placing phase, statistical analyses revealed a significant effect of Intention ($F_{(1,26.36)}$ = 14.07, $p$ < .001), with actions driven by a social intention being characterised by a longer movement time than that driven by a personal intention (estimated mean = 764 ms, *SE* = 22, and estimated mean = 689 ms, *SE* = 24, for social and personal intention respectively, $t.ratio_{(27)}$ = 3.75, $p$ = .001). The effect of Eye gaze was not significant ($F_{(1,26.87)}$= 1.51, $p$ = .230). However, the Intention × Eye gaze interaction was significant ($F_{(1,2001.91)}$= 9.72, $p$ = .002), indicating that the effect of

**Table 8.1**
*Mean Values (and Standard Deviation) for Each Kinematic Parameter Analysed as a Function of Phase (Grasping, Placing), Intention (Social, Personal) and Gaze (Visible, Non visible)*

| | | | Kinematic Parameter | | | |
|---|---|---|---|---|---|---|
| Gaze | Intention | $N$ | Peak wrist elevation (mm) | Peak wrist velocity (mm.ms$^{-1}$) | Percentage of deceleration time (%) | Movement time (ms) |
| *Grasping phase* | | | | | | |
| Visible | Social | 522 | 28.21 (14.14) | 492.36 (91.86) | 53.10 (9.31) | 764.42 (154.16) |
| | Personal | 521 | 28.43 (15.09) | 490.89 (92.63) | 51.50 (8.97) | 754.51 (170.16) |
| Non visible | Social | 515 | 26.19 (15.05) | 467.13 (83.78) | 53.17 (9.24) | 783.48 (143.82) |
| | Personal | 526 | 26.53 (14.83) | 462.87 (85.11) | 51.26 (9.13) | 770.17 (168.07) |
| *Placing phase* | | | | | | |
| Visible | Social | 522 | 24.58 (13.67) | 369.87 (67.18) | 65.12 (6.10) | 780.36 (160.66) |
| | Personal | 521 | 18.54 (12.73) | 356.68 (80.79) | 62.56 (6.48) | 690.59 (153.02) |
| Non visible | Social | 515 | 21.60 (13.55) | 364.71 (66.54) | 63.29 (6.38) | 752.31 (150.33) |
| | Personal | 526 | 17.63 (12.26) | 348.38 (89.20) | 61.38 (6.54) | 687.50 (159.70) |

*Note.* $N$ indicates the number of movements in each condition retained in the statistical analysis after outliers removal.

Intention was modulated by Eye gaze. More specifically, simple effects analysis showed that actions driven by a social intention had a longer duration than those driven by a personal intention in both gaze conditions, but this difference was larger when the gaze was visible (estimated mean = 88.10 ms, $SE = 20.4$, $t.ratio_{(29.6)} = 4.33$, $p < .001$) when compared to when it was not visible (estimated mean = 61.0 ms, $SE = 20.3$, $t.ratio_{(29.6)} = 3.00$, $p = .005$; Figure 8.3).

### 8.5.2 *Analysis of confederates' identification performances*

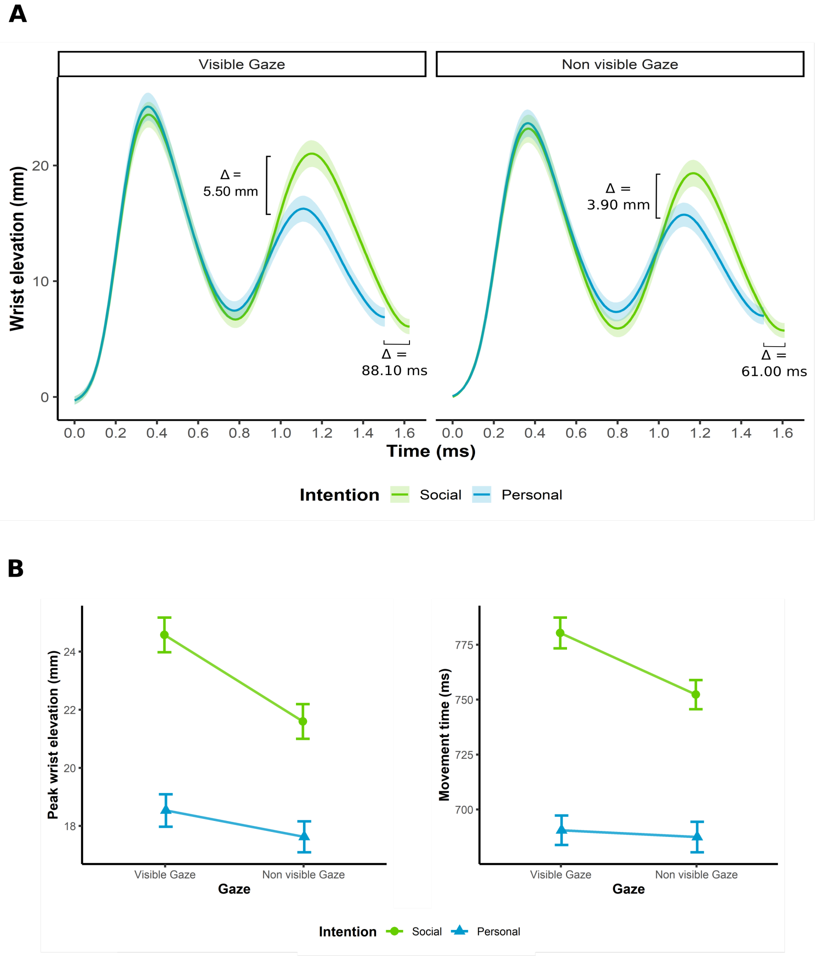
Confederates showed a higher correct identification rate of the intention subtending the actor's grasp-to-place actions in the visible gaze condition (86.90% of the intention subtending the motor actions correctly identified) than in the non visible gaze condition (76.28% of the intention subtending the motor actions correctly identified; $\chi^2_1 = 40.19$, $p < .001$; see Figure 8.4).

## 8.6 DISCUSSION

The present study aimed at determining the exact role of eye gaze cues in the expression and identification of intentions in object-directed actions and, therefore, in the success of social interactions. Two hypotheses were tested, assuming respectively that eye gaze can facilitate the expression of social intention by modulating motor kinematics (modulatory effect) or rather by dominating the expression of social intention over motor kinematics (communicative effect). To unravel these two hypotheses, participants (actors) were asked to grasp a dummy glass from an initial position and to place it to a final position, with either a social intention (having some virtual water

**Figure 8.3**

*Average Movement Time and Trajectory Height of the Grasp-to-place Actions Performed by Actors, as a Function of Intention (Social, Personal) and Gaze (Visible, Non Visible)*

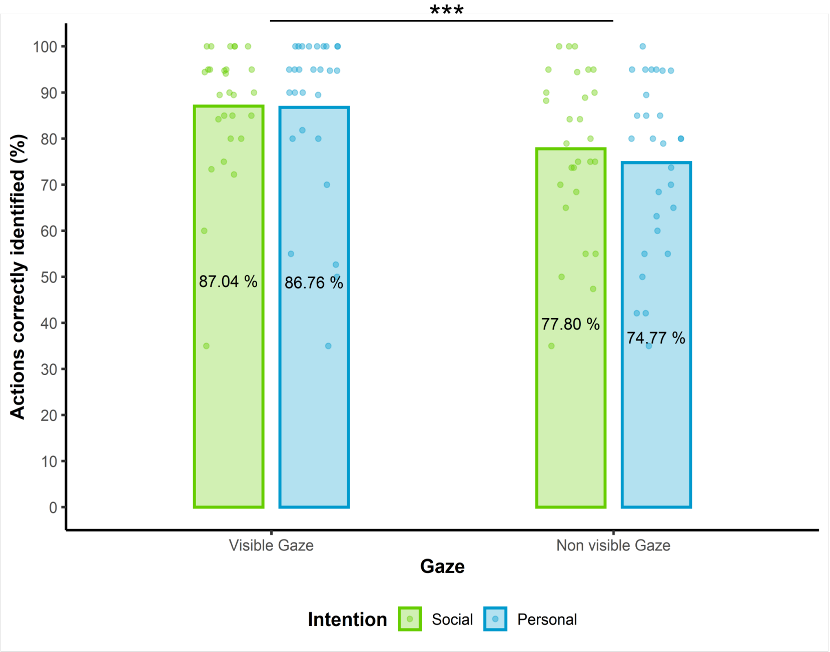


*Note.* The two bells-shaped curve represents the kinematic profile of the grasp-to-place actions. The first bell relates to the grasping phase, the second bell to the placing phase. Object-directed actions performed with a social intention were characterised by a higher trajectory, longer deceleration phase and longer movement time than personal actions during the placing phase. The difference between social and personal actions in terms of trajectory height and movement time was greater when eye gaze was visible compared to when it was not visible. Δ symbol indicates the estimated mean difference between social and personal actions. Ribbons indicate 95% confidence intervals.

poured into the dummy glass by a confederate) or a personal intention (pour themselves some virtual water into the dummy glass). Confederates had to identify the intention subtending the grasp-to-place actions performed by the actors and to respond accordingly (i.e., pouring some virtual water or staying still). Participants were asked not to communicate verbally. The task was executed while having access to each other's eye gaze or not. By means of this paradigm, we were able to test our hypotheses by assessing, on each trial, the impact of other's eye gaze availability on the execution of object-directed actions and on the identification of the intention with which they were

**Figure 8.4**

*Proportion of Actions Correctly Identified by the Confederates as a Function of Intention (Social, Personal) and Gaze (Visible, Non Visible)*



*Note.* Bars and numerical values indicate the total proportion of actions correctly identified, all participants considered together. Dots represent individual proportions of actions correctly identified by each participant.

produced. Overall, the results support the hypothesis of a modulatory role of eye gaze rather than a communicative one.

The first important outcome of the present study was that, in the absence of social cues related to eye gaze, the execution of grasp-to-place actions was influenced by social intention. More specifically, grasp-to-place actions were characterised by a higher hand trajectory, a longer deceleration phase and a longer movement time during the placing phase when they were performed with a social intention when compared to a personal intention. These results confirm previous studies (Becchio et al., 2008a, 2008b; Georgiou et al., 2007; Gigliotti et al., 2020; Quesque et al., 2016; Quesque et al., 2013; Vesper et al., 2016) and show that individuals tend to amplify the spatio-temporal parameters of their movements in order to convey a social intention and invite others to interact socially (Hostetter, 2011).

The second important outcome of the present study was that the effect of social intention on movement kinematics was amplified when other's gaze was available. Such amplification consisted in a wider difference in trajectory height and movement duration (in the placing phase) between social and personal actions in the presence of other's eye gaze when compared to its absence. A plausible explanation of this effect is that such spatial and temporal amplification of motor kinematic features induced by eye gaze could have the function of rendering motor actions more visually and socially salient, leading to a more communicative motor performance (Hostetter, 2011). This interpretation is also supported by the observed effect of eye gaze on temporal parameters. Indeed, results showed also a higher peak velocity and faster movement time in the reach phase, but a longer deceleration period in the placing phase when eye gaze was available compared to when it was not available. Overall, this suggests that participants reached the object faster but moved it slower and smoothlier to its final position. Such temporal differences between the reaching and placing phases induced by the presence of eye gaze is in line with the idea that, in the presence of eye gaze, motor actions are executed in a more salient manner, contributing thus to rendering the action more communicative for an observer.

Finally, and coherently with the explanation just reported, the third important outcome of the present study concerned the effect of eye gaze availability as social cue on the observer. When analysing the effect of eye gaze cues on the intention identification by the confederates, results showed that the percentage of actions correctly identified was higher when others' eye gaze was visible (86.90%) than when it was not visible (76.28%). These results confirm therefore that the modulatory effect of eye gaze cues on social intention-related motor kinematics play a crucial role in the success of social interactions. However, it is worth noting that when the eye gaze was not visible, the percentage of action correctly identified was still quite high. This percentage can be compared to a previous study conducted by Lewkowicz et al. (2015), using a similar paradigm to the one of the present study. The authors asked participants to watch a video showing a hand grasping an object and displacing it to a final position, with either a personal or social intention. Participants' task was to identify the intention with which the grasp-to-place actions were performed. In the videos, no other cues than the actor's arm and object displacement were available. The authors found that although participants had the feeling of responding randomly, they were nonetheless able to correctly identify the intention subtending the grasp-to-place action in 60% of the cases (i.e., above chance). Taken as a whole, the previous and current results lead to the conclusion that intention understanding is possible from mere kinematics observation (Lewkowicz et al., 2015). Nevertheless, real interaction situations constitute a richer and better context than mere video observation and access to eye gaze significantly improve the quality of social interaction.

The identification of a modulatory role of eye gaze and the better identification of intentions when eye gaze is available constitute a novelty compared to the existing literature. Indeed, previous studies have shown that the presence of eye gaze influenced the movement deceleration phase (Ferri et al., 2011; Innocenti et al., 2012) or that eye-level impact movement's trajectory height (Quesque & Coello, 2014). The present results extended these findings and highlighted for the first time that eye gaze cues do not only induce a spatial deviation of trajectories, but that it also plays a crucial role in the success of social interaction, by facilitating the expression and the understanding of the intention.

In addition to the main outcomes reported so far, the novelty of the present study resides also in the approach used to explore the question of the concurrent role of eye gaze and social intention on grasp-to-place actions execution and observation. Firstly, most of the previous studies focused on the effect of eye gaze on the execution of actions produced in reaction to a request expressed by another individual (e.g., Ferri et al., 2011; Sartori et al., 2009b). On the contrary, the present study assessed the effect of eye gaze on actions performed purposefully with the aim to convey the intention to include another person in the motor performance. To our knowledge, only the study of Quesque and Coello (2014) has addressed a similar question in the past, but using a less ecological paradigm than the present one.

Moreover, in the present study both actors and confederates were naive participants, unlike to antecedent paradigms involving dyads where one of the two participants was always an accomplice of the experimenter (e.g., Ferri et al., 2011; Innocenti et al., 2012; Quesque & Coello, 2014; Quesque et al., 2013; Scorolli et al., 2014). As a consequence, these studies investigated either the performance of the actor, or the one of the confederate, but not the two simultaneously, which represents a key aspect of the present study. Finally, the confederates had to decide by themselves how to respond, on the basis of how they interpreted the actor's kinematic variations induced by the intention behind the motor action. This constitutes a further novelty with respect to the literature, where confederates' responses were usually triggered by an external auditory signal indicating whether it was up to them or not to perform the following action (e.g., to use the object; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013). Taken together, these methodological details allowed us to study the effect of eye gaze and social intention in both actors and confederates, and in a more ecological and spontaneous context than what has been previously done.

## 8.7 CONCLUSION

To conclude, the higher percentage of actions correctly identified and the more evident difference in kinematic variations between grasp-to-place motor actions driven by either a social or personal intention are in accordance with the hypothesis of a modulatory role of eye gaze. Eye gaze cues participate in the expression of social intention by interfering with the execution of object-directed motor actions. The resultant is a richer social context that facilitates action understanding by an observer, by allowing them to more easily identify the intention subtending others' actions and respond in an appropriate way. In a broader perspective, this interaction between eye gaze and kinematics cues allowing the expression and understanding of the individuals' intentions corroborates the idea that social interactions are multi-cued. Moreover, it supports the idea that through the co-occurrence bodily, action, gaze, facial and paraverbal cues, sense making during social interaction is the result of a coordination process and the establishment of behavioural synchronicity. Further studies would be necessary to understand the dynamics of gaze contacts and how they correlate with motor kinematic variations.

Moreover, it would be valuable to conduct future experiments to investigate gaze-contact dynamics as a function of inter-personal intention and social constraints of object-oriented motor tasks. Finally, the present findings pave the way for new research paths in clinical psychology, by raising the question of a potential impairment of the gaze-kinematic cues interplay in social cognition deficits.

# 9

# THE ROLE OF SHARING A PHYSICAL SPACE IN OBJECT-DIRECTED ACTIONS

## 9.1 RATIONALE OF STUDY 5

The results presented in Chapters 7 and 8 (along with previous empirical evidence presented Chapter 3) demonstrated that the effect of the social intention (i.e., the intention to include another person in an interaction) on object-directed action execution in PPS depends also on the features of the final spatial target of the motor action (i.e., the task-related motor constraints) as well as on others' eye-gaze cues availability. These results suggested therefore that motor factors modulate the effect of social ones when individuals exploit PPS during social interactions. In Chapter 5 and 6, I also showed that the way individuals exploit PPS depended on the presence of other individuals, on their possibility to execute an action and on the rewarding outcomes resulting from these actions.

In light of these data, a last question arises logically: Are the spatio-temporal amplifications induced by the social intention directly related to a communicative purpose, or are they rather intrinsically related to the sharing of a physical co-action space? In order to shed light on that issue, we conducted an experiment in which participants were required to perform an object-directed action following either a personal or a social intention, while interacting with another individual through a video-conference system. In this Chapter, I will present the preliminary results issued from this study, which suggested that the effect of social intention observed in face-to-face interactions, where individuals share a physical workspace, disappear when the interaction is mediated by a visio-conference system, creating thereby a virtually shared space.

## "Screens make us less social": The effect of social intention on action kinematics is intrinsically related to the sharing of a same physical space

Gigliotti, M.F., Bartolo, A., & Coello, Y.

*In preparation - Preliminary results*

### 9.2 ABSTRACT

Previous empirical evidence demonstrated that the execution of object-directed actions is impacted by the social intention (i.e., the intention to involve another person in the interaction). This effect was also found to be modulated by the spatial proximity between the agents involved in the task. However, it is not known yet whether the motor deviants induced by the social intention derive from the communicative nature of the interaction, or rather from the sharing of a physical co-action space. To clarify this issue, we asked participants to displace a glass to pour themselves some water (pursuing a personal intention) or to have some water poured by a confederate (pursuing a social intention). The novelty was that the confederate sat around a table located in a different room and interacted with participants through a video-conferencing system. Results revealed that the amplification of kinematic parameters induced by the social intention classically observed in face-to-face interactions, where individuals share a physical workspace, was not observed when the interaction was mediated by an interface, embedding the interaction in a virtually shared space. Overall, these findings suggest that the execution of object-directed actions in social context depends on the sharing of a physical space between the two individuals.

### 9.3 INTRODUCTION

The execution of object-directed manual actions has been found to be influenced not only by the features of the manipulated objects (Cuijpers et al., 2004; Eastough & Edwards, 2007; Fikes et al., 2015; Gentilucci et al., 1991; Gentilucci, 2002; Paulignan et al., 1991; Paulun et al., 2016; Santello & Soechting, 1998), but also by higher-level factors, such as the final scope of the action (e.g., grasp-to-throw, grasp-to-use; Ansuini et al., 2008; Ansuini et al., 2006; Naish et al., 2013; Sartori et al., 2011), motor goal (i.e., the task-specific spatial target of an action; Gigliotti et al., 2020; Marteniuk et al., 1987) and more interestingly, social intention, namely the intention to include another person in the interaction (Gigliotti et al., 2020; Jacob & Jeannerod, 2005).

The effect of social intention on the execution of object-directed actions was observed in motion capture studies, which showed that when such actions are executed with the intention to include another person in the interaction, participants perform slower and ampler movements than when they realise the same action with a personal intention (Becchio et al., 2008a, 2008b; Georgiou et al., 2007; Gigliotti et al., 2020; Quesque et al., 2016; Quesque et al., 2013; Vesper et al., 2016). It was suggested that these spatio-temporal motor variants would contribute to render the gesture more communicative (Hostetter, 2011) and salient for an observer eventually involved in the task (Ansuini et al., 2008; Becchio et al., 2012; Cavallo et al., 2016; Elsner et al., 2012; Lewkowicz et al., 2013; Lewkowicz et al., 2015; Manera et al., 2011; Quesque et al., 2016; Sartori et al., 2009b; Sebanz & Knoblich, 2009; Stapel et al., 2012).

Others studies have shown that gaze contact between two individuals impact the execution of object-directed actions (Ferri et al., 2011; Innocenti et al., 2012; Quesque & Coello, 2014; Sartori et al., 2009b; Scorolli et al., 2014). For instance, it has been shown that the motor trajectory height increased when the observer eye-gaze level was set 5 cm higher than the participant's eye-level (Quesque & Coello, 2014). Moreover, the kinematic difference between personal and social action was reduced in the absence of others' eye-gaze, and the observers showed more difficulties in identifying the intention underlying the performed action (see Chapter 8).

Finally, by manipulating the vicinity between the two agents of the task, Quesque et al. (2013) found that the spatio-temporal amplification of actions' kinematic features depended on the perception of the possibility to actually interact with another agent. Indeed, authors observed that object-directed actions were characterised by longer reaction times (i.e., longer latency before starting the movement) and lower acceleration peaks when the confederate sat in the participants' reachable space compared to when they sat in their extrapersonal space. In addition, these effects were not observed when the confederate sat within the reachable space, but while assuming a passive posture (i.e., not taking part to object manipulation task). Finally, no effect of sharing a reachable space was observed on movement duration nor on movement trajectory height. To explain these results, authors proposed that the execution of grasping actions is influenced by spatial proximity only when individuals perceive the possibility to enter in interaction.

Despite being interesting, the exact nature of the spatio-temporal amplification of movement kinematics induced by the social intention remains not fully unraveled. Indeed, it is not known yet whether the effect of social intention on motor performances is essentially functional to a communicative scope, or if it is grounded in the interaction itself, that is, if it arises from a specific use of space determined by the presence of another individual. In accordance with such hypothesis, it has been shown that the presence of other agents modify the way individuals perceive their nearby peripersonal space and act within it (e.g., Coello et al., 2018; Gigliotti et al., 2021; Teneggi et al., 2013). Moreover, these results do not fully clarify whether sharing a physical space while actually interacting impact the execution of object-directed actions. Such question is even more pertinent nowadays, were more and more interactions occur in virtual spaces. Indeed, one might asks whether the effect of social intention observed in face-to-face interactions (where individuals share a physical workspace) is still present when the interaction is mediated by an interface, such as a screen supporting video-conference, embedding thereby the interaction in a virtually shared space.

In order clarify that issue, we asked participants to grasp a dummy glass from an initial position and place it to a final position in order to pour themselves some water (pursuing a personal intention) or to have some water poured by a confederate (pursuing a social intention). During the task, the confederates interacted with the participants by serving some water in response to the socially-driven actions. However, differently from previous studies, the confederate sat around a table located in a different room and interacted with participants through a video-conferencing system.

## 9.4 METHOD

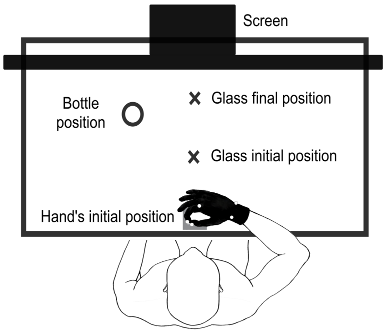
### 9.4.1 *Participants*

A total of 20 (12 females) healthy participants took part in the experiment. They were aged between 18 and 35 years, ($M$ = 23.7 years, $SD$ = 4.67), they were all right-handed (mean laterality quotient = 0.92, $SD$ = 0.10, assessed through the Edinburgh Handedness Inventory; Oldfield, 1971), they declared having normal or corrected-to-normal visual acuity and no perceptual or motor deficit. They had no knowledge about the research hypotheses and accepted to participate after giving their informed consent. The protocol was conducted in accordance with the ethical principles stated in the Declaration of Helsinki (World Medical Association, 2013).

### 9.4.2 *Stimuli and procedure*

Participants were required to gasp a dummy glass (diameter = 1.7 cm, thickness = 1 cm) from an initial position and place it to a final position (see Figure 9.1), with either a personal (to virtually serve themselves some water) or social intention (to be virtually served some water by a confederate). The confederate was an accomplice of the experimenter, who behaved as a naive participant. The confederate sat around a table placed in a separate room and interacted with participants through a screen by a video-conference system, using the web conferencing platform BigBlueButton. Wired local area network was used to connect the internet and allowed to obtain a low latency ($>$ 100 ms) between the moment the video was captured and the moment it was displayed on the viewer's screen. A second dummy bottle was placed on the confederate's table. The screen and camera filming the scene were placed so that to create the illusion that participants and confederates sat around the same table, within a reachable distance from each others' body. Participants placed the glass near the screen and confederates used the bottle as if they poured some water "through" the screen on the participants'

**Figure 9.1**
*Representation of the Experimental Setup*



*Note.* The distance between the hand's initial position and the object initial position was 20 cm. The same distance separated the object initial position from the object final position, and the object final position from the bottle position. The bottle was placed 3 cm below the level of the object final position, in order not to hide the marker on the object during the task.

glass. A visual correspondence was then created between the bottle neck end used by the confederate and the edge of the glass manipulated by the participants.

The height of participants' chairs was adjusted so that their eye-level was the same as the confederate's one, avoiding thereby an interference effect of eye-level on kinematic performances (Quesque & Coello, 2014). A trial started by a pre-recorded voice pronouncing the signals "You" or "Him". After hearing the signal "You" (personal intention), participants had to grasp and move the glass to the final position, then use the bottle placed on the side to pour themselves some water. After hearing the signal "Him" (social intention), participants had to grasp and move the glass to the final position in order to be served by the confederate. Participants had 4 s to grasp and place the glass and 4 s to use the bottle or to wait for the confederate to use it. After this delay, a beep indicated to participants to grasp the glass and place it back to the initial position, in order to get ready for the next trial. The delay of inter-trial interval varied randomly between 2 and 3 s following the beep. At the beginning of each trial, and at the beginning and the end of each action, participants were requested to pinch together their thumb and index fingers and place their hand to a fixed starting position (see Figure 9.1).

Participants performed one block of 50 personal intention trials and one block of 50 social intention trials. The order of blocks was counterbalanced across participants. The task lasted about 40 mn. A short pause occurred halfway through each block (after the first 25 trials) and between each block.

### 9.4.3 *Data recording and processing*

Participants' motor performances were recorded using Qualisys Motion Capture System and five Oqus infrared Qualisys cameras (200-Hz sampling rate, spatial resolution $< 0.2$ mm) placed on the sides of the table. The cameras were calibrated using the wand method prior to each experimental session, in order for the system to reach a standard deviation between 0.5 and 0.99 mm. The cameras tracked the Cartesian coordinates in space ($x$, $y$, $z$) of five passive markers fixed on a glove that participants wore during the task. The five markers were localised at the level of the index tip, index base, little finger base, thumb tip and scaphoid bone of the wrist. A 6th marker was placed on the dummy glass to track its position during the task and ensure that it was correctly placed on the initial and final position.

Motor performances were recorded by means of the interface QMT Connect for MATLAB installed on a computer Dell 7010. The interface connected Mocap recordings by Qualisys Track Manager (version 2.13) to the MATLAB (version 2014a) script handling the running of the task and the presentation of the auditory signals. Motor performances were then analysed by means of an in-house MATLAB script adapted from the RTMocap toolbox (Lewkowicz & Delevoye-Turrell, 2015). In line with previous literature (Gigliotti et al., 2020; Quesque & Coello, 2014; Quesque et al., 2016; Quesque et al., 2013), analyses were conducted only on the trajectory of the marker placed on the wrist, which expresses arm movements without the influence of wrist rotation. The grasp-to-place movements performed by participants were composed of two phases: a grasping and a placing phase. For each phase, four temporal and kinematic parameters were extracted: the peak wrist elevation (mm, indicating the maximum trajectory height), the peak wrist velocity ($\text{mm.ms}^{-1}$), the movement time (ms) and the percentage of deceleration time (%). For a detailed description of the computation of each parameter and the movement phase onset and end, see Quesque et al. (2013) and Gigliotti et al. (2020).

### 9.4.4 *Statistical analysis*

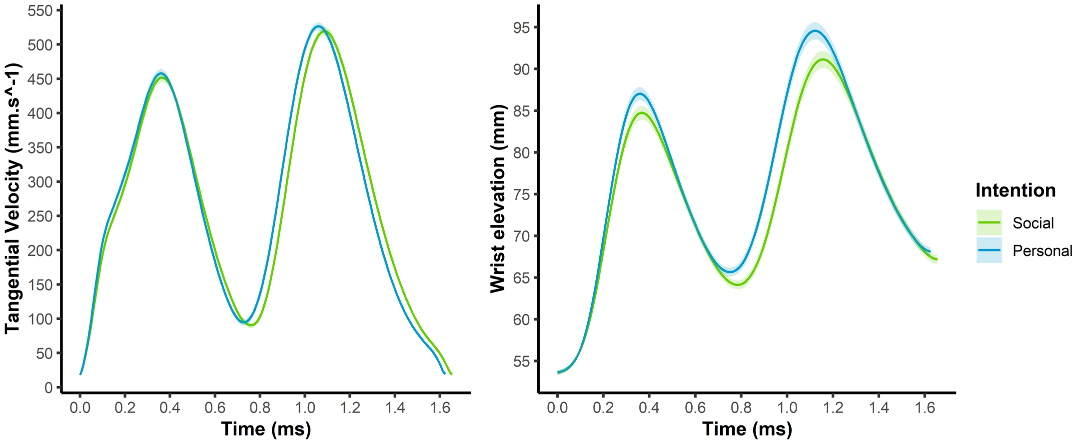
Statistical analyses were conducted on R version 3.5.1 (R Core Team 2018) and R Studio version 1.1.456. Movements were excluded from statistical analysis if they were not correctly executed (i.e., impossibility to detect at least 2 local minima and/or 2 local maxima in the trajectory analysis) or if they resulted being outliers on at least one kinematic parameter following the absolute deviation from the median method (Leys et al., 2013). In order to keep data loss below 5%, the chosen threshold for outliers' rejection corresponded to the difference from the median +/− 4 times the MAD.

Each kinematic parameter was analysed separately using the Linear Mixed-Effects Models approach (Barr et al., 2013; Brauer & Curtin, 2018; Judd et al., 2012; Matuschek et al., 2017). The chosen model (see Formula 9.1) included the Intention (Social, Personal) as repeated measures fixed-effects parameter and a by-subject random intercept and slope for the effect of the Intention (Bates et al., 2015a; Gigliotti et al., 2020; Matuschek et al., 2017) as random-effects parameter.

$$\begin{gathered} Kinematic\ Parameter\ of\ Interest \sim \\ Intention + (1 + Intention\ |Participant) \end{gathered} \tag{9.1}$$

**Figure 9.2**

*Mean Velocity and Trajectory Height Profiles as a Function of the Intention (Social, Personal)*



*Note.* Ribbons represent 95% confidence intervals.

Linear Mixed-Effects Models were fitted and analysed by means of the lmer function of the "lme4 1.1–23" (Bates et al., 2015b). The model parameters were estimated through REstricted Maximum Likelihood approach (REML) and statistically tested using the $F$ test (degrees of freedom computed using the Satterthwaite approximation; Luke, 2017) thanks to the function anova of the "lmerTest 3.0-1" package (Kuznetsova et al., 2017). The normality of model residuals and homoscedasticity were verified graphically and sum-to-zero contrasts were specified before model fitting. EMMs, summarising the model, were computed with the function emmeans of the "emmeans 1.7.1-1" package (Lenth et al., 2019) and were reported besides the relevant statistical tests in the text and in the tables. OMMs, summarising the data, were reported in tables.

## 9.5 RESULTS

Amongst an initial data set of 2000 grasp-to-place actions, 62 movements were excluded from statistical analysis, leading to a data loss of 3.10%. The temporal and kinematic parameters were computed and analysed separately for the grasping and placing phases of the preparatory action. Overall, statistical analyses did not reveal any significant difference between actions performed with a social or a personal intention, regardless of the kinematic parameter analysed. Figure 9.2 shows the similar velocity and trajectory height profiles of the grasp-to-place actions observed for social and personal actions. Table 9.1 reports the mean values and standard deviations for each parameter as a function of the Intention (Social, personal) and the movement phase (grasping, placing).

### 9.5.1 *Peak wrist elevation*

Statistical analyses revealed a non significant effect of the Intention during both the grasping (estimate = 2.18, *SE* = 1.17, $F_{(1,18.91)} = 3.52$, $p = .076$) and the placing phase (estimate = 4.10, *SE* = 2.02, $F_{(1,18.95)} = 4.11$, $p = .057$), with no statistical difference in term of trajectory height between actions performed with a social or personal intention.

### 9.5.2 *Peak wrist velocity*

Statistical analyses revealed a non significant effect of the Intention during both the grasping (estimate = 3.72, *SE* = 7.99, $F_{(1,18.87)} = 0.22$, $p = .646$) and the placing phase (estimate = 12.53, *SE* = 11.10, $F_{(1,19.01)} = 1.27$, $p = .273$), with actions performed with a social intention not differing from actions performed with a personal intention on peak wrist velocity.

### 9.5.3 *Percentage of deceleration time*

Statistical analyses revealed a non significant effect of the Intention during both the grasping (estimate = -0.73, *SE* = 0.56, $F_{(1,19.16)} = 1.72$, $p = .205$) and the placing phase (estimate = 0.15, *SE* = 0.43, $F_{(1,18.93)} = 0.12$, $p = .736$), with actions performed with a social intention not differing from actions performed with a personal intention on the percentage of deceleration time.

### 9.5.4 *Movement time*

Statistical analyses revealed a non significant effect of the Intention during both the grasping (estimate = -25.04, *SE* = 13.71, $F_{(1,18.98)} = 3.34$, $p = .083$) and the placing phase (estimate = -6.08, *SE* = 14.68, $F_{(1,18.98)} = 0.17$, $p = .683$), with actions performed with a social intention not being characterized by a different movement time than actions performed with a personal intention.

## 9.6 DISCUSSION

The present study aimed at assessing whether the effect of social intention on the execution of object-directed actions resulted from a communicative purpose (gestures are amplified to better communicate) or whether it is intrinsically related to a sensorimotor processing that occur as a consequence of sharing a same physical action space. Participants were required to grasp a dummy glass from an initial position and place it to a final position with either a personal intention (pour themselves some water) or a social intention (having some water poured by a confederate). The novelty was that the confederate sat around a table located in a different room and interacted with

**Table 9.1**

*Mean Values (and Standard Deviations) of Each Kinematic Parameter as a Function of Phase (Grasping, Placing) and Intention (Social, Personal)*

| | | Kinematic Parameter | | | |
|---|---|---|---|---|---|
| Intention | *N* | Peak wrist elevation (mm) | Peak wrist velocity (mm.ms-1) | Percentage of deceleration time (%) | Movement time (ms) |
| *Grasping phase* | | | | | |
| Social | 964 | 33.87 (13.03) | 501.34 (92.82) | 51.56 (8.52) | 770.47 (124.05) |
| Personal | 974 | 36.05 (13.42) | 503.62 (84.37) | 50.79 (8.13) | 747.42 (116.12) |
| *Placing phase* | | | | | |
| Social | 964 | 39.95 (16.72) | 576.78 (82.41) | 65.10 (5.35) | 849.07 (146.00) |
| Personal | 974 | 43.71 (17.22) | 588.95 (68.28) | 65.29 (5.86) | 844.62 (126.05) |

*Note. N* indicates the number of movements in each condition.

participants through a video-conferencing system. The screen and camera filming the scene were placed to create the illusion that participants and confederates sat within a reachable distance from each others' body.

Preliminary results showed no significant differences between the actions performed with a social and personal intention on any of the kinematic parameters analysed. As reported in previous literature, the actions performed with a social intention are usually characterized by a greater trajectory height, longer movement duration and longer deceleration phases, which result in a gesture executed in a more amplified and gentle way (e.g., Becchio et al., 2008a, 2008b; Georgiou et al., 2007; Gigliotti et al., 2020; Quesque et al., 2016; Quesque et al., 2013; Vesper et al., 2016). Nevertheless, in the present preliminary study none of these effects was observed. Moreover, when approaching data analysis from a descriptive angle, the only trend observed concerned the maximum elevation of the wrist, expressing the trajectory height, which tended to be higher for personal actions compared to social actions. Such result was only marginally significant, and by the way, it suggested the presence of an opposite effect of intention compared to the effect classically observed in the literature.

In light of the present results, several considerations deserve to be highlighted. Firstly, despite the absence of significant effects yielded by the statistical analysis, we can not conclude on the absence of effect. In such context, Bayesian statistical approach would here be appropriate to assess whether there is a truly equivalence between the kinematic profiles of personal and social actions (i.e., Bayes factor; Lakens et al., 2020). Secondly, it would also be important to test whether a similar pattern emerges when using a mixed-trials randomised design, alternating randomly personal and social trials, instead of a randomised block design. Although the effect of the intention on motor performances has been observed when using both types of paradigm (e.g., Gigliotti et al., 2020; Quesque et al., 2016; Quesque et al., 2013), one can not exclude that the type of design might have had an impact on the obtained results. Indeed, one might hypothesise that interacting through screen constitutes a less spontaneous and natural situation when compared to live interactions. Therefore, using a block design could contribute to render the situation even less ecological.

Contingent to the realisation of further statistical analysis and methodological verification, we can speculate that interacting through a screen lead individuals to differently use space and non-verbal cues when interacting with others. Virtual interface-mediated interactions are indeed known to be characterised by a paucity of non-verbal cues and feedbacks (Walther & Burgoon, 1992). This results in a decreased feeling of social presence, namely, the feeling of being in the presence of another individual whose emotions and thoughts can be accessed (Biocca et al., 2003). Moreover, gaze exchanges can be altered during video-conferencing interactions and are strongly influenced by technical configurations, such as the position of the webcam (Bohannon et al., 2013). In light of these observations, we might speculate that non-verbal communication in interface-mediated social interaction relies on a different exploitation of non-verbal cues, which might depend on the constraint related to the sharing of a physical space. Indeed, live social situations constitute a specific context, where several behavioural and physiological adjustments occurs. It has been shown for instance that sharing a physical proximal space modulates the way attention is allocated to the surrounding stimuli (e.g., Szpak et al., 2015), and physiological responses (e.g., Bogdanova et al., 2022; Fossataro et al., 2016; Ioannou et al., 2014). This suggests that when sharing a space, a series of bodily signals and processes are recruited to adjust homeostasis and eventually prepare the individual to appropriately react (Coello & Cartaud, 2021). Finally, if the spatial amplification of motor performances is due to the sharing of a space, this might question the idea that the social-induced motor deviants are the consequence a communicative purpose, as previously reported (Hostetter, 2011).

## 9.7 CONCLUSION

The preliminary results of the current study did not show a significant effect of social intention on the execution of object-directed actions when interacting through a screen. Moreover, descriptive analysis of the data showed that kinematic profiles of object-directed actions performed with a social intention differed from what is classically observed in literature. Specifically, social actions were characterised by a lower trajectory height than personal actions. These results might suggest that the spatio-temporal modulation of motor performances induced by the social intention does not uniquely serves a communicative purpose, but seems also related to the sharing of a physical space. Furthermore, these findings suggest that the way individuals exploit space and execute their actions changes when the interaction take place in a virtual environment. Further studies are needed to confirm such hypothesis and eventually determine the impact of screen-mediated interactions on people's motor during social interactions.

# Part III

# GENERAL DISCUSSION

# 10

# DISCUSSION OF THE CONDUCTED STUDIES

## 10.1 OVERAL SUMMARY

The present thesis aimed at examining how motor and social factors influence the construction of PPS, namely the action space surrounding the body, where individuals can easily interact with objects and people. In the introduction, I showed that stimuli occurring within PPS benefit from a multisensory integration and sensori-motor processings, which facilitate the programming and execution of purposeful or defensive actions directed towards these stimuli. Furthermore, I presented evidence for the role of PPS in social interactions, showing that PPS undergoes plastic and dynamic changes in the presence of other individuals and during the execution of collaborative tasks. Such changes would lead to the creation of a “we space”, namely a shared action space where two (or more) individuals engaging in an interaction would be sensitive to salient stimuli of common interest and prepare to function in a “we mode” (Gallotti & Frith, 2013; Pezzulo et al., 2013). Finally, I evoked the Action Field Theory of PPS by Bufacchi and Iannetti (2018), the theoretical framework that I adopted in the context of the present thesis and that I combined with the empirical findings by Coello et al. (2018) to support the hypotheses tested. Within this framework, PPS was conceptualised as a multiple response-fields zone, where each response-field would consist in a portion of space associated with a functional value determining the most pertinent action to perform. Such value would not be constant in time, but rather computed and attributed instantaneously as a function of the ongoing task demands, stimuli and context features in a given time and space.

Grounding on this theoretical background, the aim of the present thesis was to examine the influence of motor and social factors on PPS functional construction when concurrently involved during the execution of a task. For this purpose, I considered that since PPS acts as a perception-action interface (see Brozzoli et al., 2012), its construction involves two dimensions: a perceptual and representational dimension and a motor dimension. Specifically, I decided to assess PPS *representation* (i.e., the representation of the space immediately surrounding the body) and what I defined as PPS *exploitation* (i.e., the action selection process within PPS, and thus, individual’s behavioural responses in such space). To this aim, I employed reachability-judgment task to assess the extent of PPS representation (in Study 1 and 2). In order to examine PPS exploitation, I employed a stimuli-selection task (in Study 1 and 2) and a task requiring the execution of an object-directed action (in Study 3, 4 and 5). In all the five studies, the task were executed in collaboration with a confederate. The initial hypothesis was that motor factors would exert an effect on PPS representation and exploitation, and that this effect would be modulated by social factors.

## 10.2 OVERVIEW OF THE MAIN RESULTS OBTAINED

The initial hypothesis supposing that social factors would modulate the effect of motor factors on PPS representation and exploitation was verified in Study 1 and 2. Nevertheless, Study 3, 4 and 5 focused on PPS exploitation, and showed that the contrary was also true. More specifically:

**Study 1** (Chapter 5) showed that during the execution of a collaborative motor task, the prospects of obtaining a reward in space influenced individuals' PPS exploitation and representation. However, this effect appeared to be modulated by the constraints related to the social context, namely by the will to avoid others' space invasion.

**Study 2** (Chapter 6) explored whether the effects observed in Study 2 depended on the degree of involvement of the two individuals in the motor task. For this purpose, individuals were asked to perform motor actions susceptible to be rewarded in front of an observer (or to observe a confederate performing the motor actions). In such situation, results showed that action rewards and the social context modulated PPS representation and exploitation differently than when both individuals are actively involved in the motor collaborative task.

**Study 3** (Chapter 7) showed that during the execution of object-directed actions, the features of the final spatial target of the motor action (i.e., the task-related motor constraints) are prioritised over the intention to involve another individual in the interaction (i.e., the social intention).

**Study 4** (Chapter 8) went one step further and showed that the social cues offered by eye gaze modified the execution of object-directed actions in space and facilitated the recognition of the intention with which they were executed by an observer. This result suggested that eye-gaze has not simply a communicative role, but that it also acts as a spatial attractor influencing the way individuals use space during the execution of motor actions.

**Study 5** (Chapter 9) suggested finally that sharing a physical action space is responsible for the specific way individuals use space to communicate their intention to interact with other individuals. If the interaction takes place in a virtual space, the motor pattern characterising object-directed actions is different than the one classically observed in face to face interactions.

From a wider perspective, two major findings emerged when considering all the five studies together: (a) Social and motor factors are hierarchically taken into account when attributing a certain functional value to PPS and (b) such value attribution would occur at two different levels: a perceptual-representational level and a motor level. These two major findings will constitute the two axis structuring the general discussion. In the following sections, I will combine the results from Study 1 and 2, and then from Study 3, 4 and 5 in order to provide a more in-depth discussion of the main aspects highlighted by the current research work.

## 10.3 THE EFFECT OF ACTION REWARDS AND SOCIAL CONTEXT ON PPS CONSTRUCTION

Study 1 and 2 allowed to clarify the role of action rewards and social context constraints on PPS representation and exploitation. In the present section we will discuss in detail these results. For a sake of clarity and fluid progression of ideas, I will first discuss the results concerning PPS exploitation and next, the ones concerning PPS representation.

### 10.3.1 *Social context modulates the effect of action rewards on PPS exploitation*

As regards PPS exploitation, Study 1 and 2 showed that individuals tended to act mainly in the portion of space associated with a higher probability to obtain a reward (Coello et al., 2018). These results indicated thereby that action selection process depends on reward prospects in space. As a consequence, reward prospects can be taken into account when computing the action-related value attributed to a given portion of space. Nevertheless, if this highly-valued portion of space coincides with the space near a confederate's body, individuals tend naturally to avoid such space, and perform quite few actions within it. They rather prioritise their own near space and, only in a second time, they start acting in confederate's PPS. As previously stated, these results suggest that avoidance of others' space invasion modulates the effect of action rewards, by delaying the exploitation of space when rewards are located in the confederate's PPS.

In addition, the Study 1 and 2 showed that the delay (expressed here in terms of number of motor actions performed) preceding the exploitation of others' PPS relies on the individual's degree of motor involvement in the interaction. In our early study (Coello et al., 2018), we observed that, when acting alone in a workspace, participants began to exploit consistently the space associated with higher reward prospects after approximately 30 manual reaching actions. Study 1 showed that, when co-acting with a confederate in a shared workspace, if the space associated to higher rewards prospects coincided with the confederate's PPS, participants exploited this space only after approximately 66 manual reaching actions (see Section 5.5.2). Nevertheless, Study 2 showed that if the confederate was not actively involved in the motor task (e.g., observing), participants took even more time before exploiting the confederate's PPS. Accordingly, this occurred only after approximately 168 manual reaching actions (see Section 6.4.1.1). Therefore, the exploitation of the space associated with higher reward prospects occurs rapidly when the individual act alone in the workspace, later when co-acting with a confederate and even later when acting in front of a passive confederate.

Taken together, these findings suggest that space exploitation depends not only on action reward prospects in space, but also on the will to respect others' personal space and that the confederate's passive or active attitude during the task plays an important role in such process. These results echoes previous findings on PPS regulation as a function of interpersonal distances and comfort feeling (e.g., Cartaud et al., 2018; Quesque et al., 2017), and also, they provide support for the hypothesis that other's action possibilities are taken into account when constructing PPS (e.g., Iachini & Ruggiero, 2021). More generally, these findings suggest that social context-related factors (e.g., respecting others' personal space, others' passive or active attitude and action possibilities) would thereby be integrated in the computation of the action value attributed to a portion of space, in combination with the effect of action rewards.

### 10.3.2 *Social context and action rewards exert a combined effect on PPS representation*

As regards PPS representation, Study 1 and 2 showed that social and motor factors exert a combined effect. More specifically, results showed that the execution of a motor task in collaboration with a confederate counterbalance the effect of action rewards on PPS representation. Indeed, after the execution of the collaborative task, individuals' PPS representation was found either to extend or to remain stable, but never to constrict, not even when action rewards were mainly located in the space close to the individual's body. This result is in contradiction with what was previously found by Coello et al. (2018), who observed a constriction of PPS representation after that individuals obtained a higher proportion of action rewards in their proximal space. Such extension effect (and absence of constriction) can be explained by several factors related to the social context.

First, as advanced in Study 1, PPS extension in a collaborative context might result from the integration of others' action outcomes (and rewards) to one's own PPS representation. Such explanation would suppose an additive effect of self- and other-generated motor actions rewards. Therefore, if rewards prospects are higher in the distal space and action rewards are obtained by both the individuals and their confederate, PPS representation extends, as a result of the sum of self and others-generated action outcomes. Alternatively, if reward prospects are higher in the individual's proximal space, PPS representation does not constrict (as in Coello et al., 2018), suggesting that the rewarding outcomes of others counterbalance the effect of one's own rewarding outcomes.

Nevertheless, this explanation does not seem sufficient to exhaustively explain the observed effects. Indeed, as shown by Study 2, PPS representation was found to not constrict when rewards were located in the near space, even when the confederate observed passively the task and therefore, did not execute any motor action susceptible to provide rewards. Therefore a second explanation might be that even if the proximal space is "motorically" salient (i.e., endowed with a high action reward-related value; Coello & Cartaud, 2021), in a situation of interaction with a near confederate, individuals would not constrict their PPS and preserve a certain personal action space. Such absence of constriction of PPS representation echoes previous findings on PPS regulation and interpersonal distances, and could be related to the maintenance of a safety buffer zone (e.g., Cartaud et al., 2020; Cartaud et al., 2018; Graziano & Cooke, 2006).

A third final explanation for the PPS extension in social context could rely on the fact that in a collaboration context, PPS representation of both individuals would merge in order to create a unique, shared action space, allowing them to function in the "we mode". Such merging would be induced by the demands of the task itself, which requires individuals to act on, and therefore direct their attention to an object of common interest. Within such "we space", individual would thereby easily function in a "we mode" (Gallotti & Frith, 2013; Pezzulo et al., 2013).

To summarise, in a collaborative social context, individuals would adjust their PPS representation: (a) Following the integration of other's action outcomes and/or (b) to maintain a certain safety zone, or/and (c) to eventually generate a shared action space serving the social interaction. These three factors related to the social context could contribute to the attribution of a given value to a portion of space. In light of these consideration, one question arises logically: What is the nature of PPS adjustment in social context? Does it consist in a merging of self and other's PPS, or is it rather a simple addition of other's PPS in one's own PPS, keeping thereby a separation in-between the two? The following section will discuss these issues.

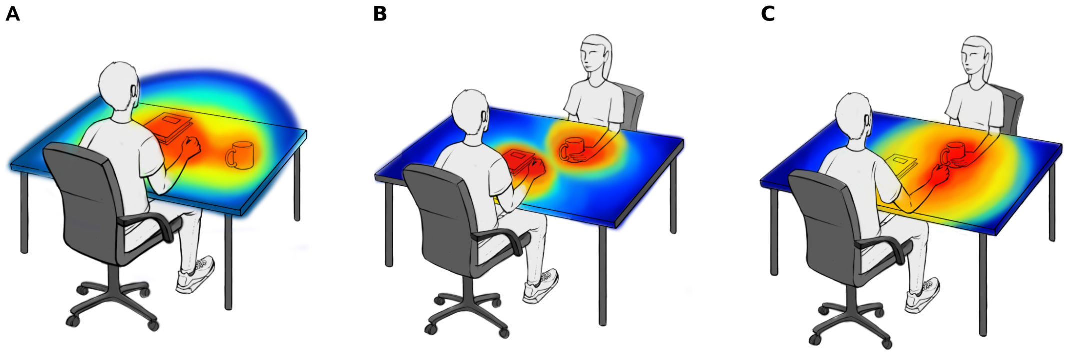
### 10.3.3 *Merging or extending PPS?*

In a situation of social interaction, PPS extension can take different forms as a function of the type of task and involvement degree of the two individuals. Figure 10.1 shows such different potential cases. In panel A, an individual sits alone around a table. In this case, PPS encompasses the space immediately in front of their trunk, and greater salience is attributed to the space occupied by the objects of interest (i.e., a book and a cup) and by the body part used (i.e., the right arm). Even greater salience is attributed to the cup and the hand, as their spatial proximity prompts an easier and faster use.

Panel B shows the case where a confederate would be sitting in front of the individual, and acting on an object of their own interest. In this case, individual's PPS would extend and encompass the confederate's PPS, but not the space in-between the two of them. Empirical data supporting this case was provided by Maister et al. (2015). By means of a multisensory integration task, these authors observed that following a shared sensory experience (i.e., a tactile stimulation administered synchronously to the two individuals' face), faster detection of tactile stimulus was observed when a concomitant auditory stimulus was presented in the space near the participant as well as near the confederate.

**Figure 10.1**

*Extension vs. Merging of PPS*



*Note.* A. When acting alone: A higher value (red halo) is attributed to the portion of space occupied by the objects of interest (the book and the cup) and by the body part used (along with its position in space) to interact with them. The space separating the trunk from the object of interest and the hand is also attributed a given value, as it serves as frame of reference for manual action execution (McIntyre et al., 1998), although to a lesser extent (yellow halo). B. When a confederate is present in the near space and act on their own objects of interest: A higher value is attributed to the space occupied by both our and the confederate's object of interest. The two foci-map illustrates the sensitivity of an individual to the space where their confederates acts (with an eventual extension of their own PPS to encompass this area), but without necessarily creating a merged, shared space. C. When cooperating and executing a motor action on an object of common interest: The individual's and confederate's PPS merges in order to create a "we-space" serving the social interaction.

Nevertheless, no facilitation effect was observed when the sound was presented in the space between the two[1]. Such a change in PPS might allow the individual to monitor the events happening in others' space, although the situation does not require any action from the individual within the others' space. This case would eventually correspond to the pattern observed in Study 2, where the observer extended PPS representation to encompass the space of the actor despite not acting in it.

Finally, Panel C shows the case in which two individuals would be engaged in the execution of a co-action task (i.e., a task during which the action of the one will be followed by a complementary action by the other). In such case, we could speculate that the two individuals would merge their respective PPS to create a shared action space (Pezzulo et al., 2013). Such type of change was observed by Teneggi et al. (2013). Differently to Maister et al. (2015), Teneggi et al. found that after the execution of a cooperative economic game, the distance at which the concomitant sound started to facilitate tactile stimulus detection shifted in space, towards the confederate. This case would eventually correspond to the pattern observed in Study 1, where the two individuals reported an increase of their PPS representation after co-acting in a shared space for a common goal.

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[1] Maister et al. (2015) proposed to define the observed change as a *remapping* rather than an *extension* of PPS. More specifically, "Events approaching the other's body [would be remapped] onto one's own PPS representation" (Maister et al., 2015, p.6).

## 10.4 A SHARED SPACE FOR SHARED ACTIONS

In the previous sections, I discussed the modulatory role that social factors exert on motor ones in PPS construction (when considering both PPS representation and exploitation). Nevertheless, Study 3, 4 and 5 (which focused specifically on PPS exploitation) showed that the reverse is also true, namely that the effect of social factors might be modified by the motor ones.

Study 3 showed indeed that the spatio-temporal motor deviants of a grasp-to-place action induced by the social intention were smaller when the task required to fast place the object on a big target when compared to a small one. In addition, Study 4 showed that even eye gaze, which is classically considered as a social interaction cue, was found to modulate the spatio-temporal features of the executed action. Finally, Study 5 showed that sharing a physical space might be a crucial factor determining the specific spatio-temporal motor pattern associated with the expression of the social intention.

As a whole, these findings reveal that social interactions are grounded and embedded in a physical and motor context, which determines the way individuals move in space to communicate non-verbally with other individuals. On a broader perspective, it could conceivably be hypothesised that the motor pattern associated with the expression of the social intention is the resultant of a learning process beginning in childhood and evolving throughout lifetime. If exploiting space in a specific way generate the wished reaction in a confederate (e.g., capturing their visual attention with wider movement and establishing gaze contact in order to signal the intention to interact), the system would therefore select such behaviour and repeat it in future similar situations. Therefore, apprehending space would be at the core of the establishment of a behavioural synchrony between two individuals: We learn to behave and move in a certain way in order to render our gestures understandable by others, and consequently, we become able to decode similar patterns in other's behaviour.

Such hypothesis might find support in studies conducted on clinical populations presenting social interaction deficits. For instance, interesting insights emerged from a recent study, which compared the performances of typically developing (TD) children vs. children with autism spectrum disorder (ASD) in kinematic encoding and intention readout of others' movements (Montobbio et al., 2022). Results showed that TD children were better at detecting the kinematic variations during the observation of TD actions, while ASD were better at detecting the kinematic variations of ASD actions. Nevertheless, while TD were able to disentangle the intention associated with such actions, ASD children showed several difficulties and performed below chance level. Such results were explained by a kinematic dissimilarity underpinning the motor pattern of TD and ASD children and it was suggested that the motor pattern of ASD would be less informative than the one of TD. Together with the difficulties observed in motor adjustment to the final goal of an action (Fabbri-Destro et al., 2009), external visual features integration during action planning (Dowd et al., 2012) and differences in multisensory integration of near-body stimuli (Mul et al., 2019), these findings provide new insights to understand social interaction difficulties in connection with space coding.

# 11

# TOWARDS A FUNCTIONAL CONSTRUCTION OF PPS

## 11.1 A MODEL ACCOUNTING FOR PPS CONSTRUCTION

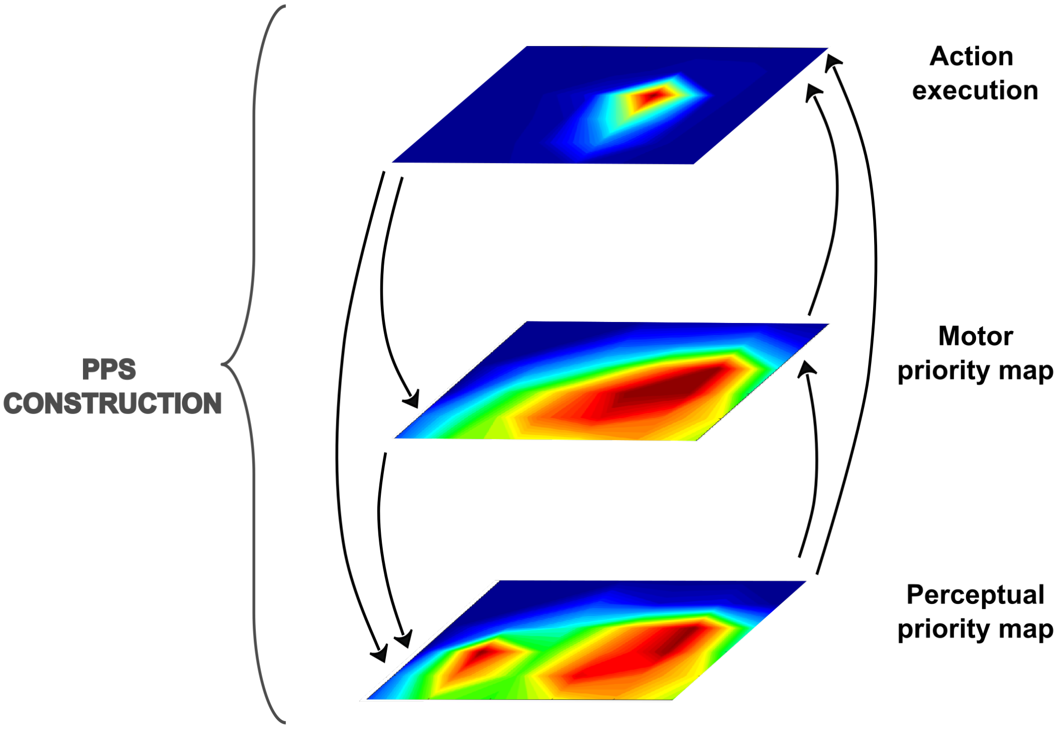
### 11.1.1 *A multi-layer construction of PPS*

In light of the findings of the present thesis, a new model could be proposed to offer an integrative view of PPS construction. As shown by Figure 11.1, such model would be composed of three layers: a *perceptual priority map layer*, a *motor priority map layer* and an *action execution layer*. It is important to note that these maps would not be constructed along a horizontal 2D plane, but they would rather extend in the three dimensional space closely surrounding the body.

The first layer, the *perceptual priority map* layer, would correspond to the perceptual representation of near-body space, stemming from the integration of different sensory inputs (e.g., visual, auditory, tactile). Such perceptual representation would owes to Bufacchi and Iannetti (2018)'s conceptualisation the idea of being divided into multiple response-fields, each endowed with a specific value. For instance, the space occupied by a cup that we want to grasp would be associated with a higher value (red-coloured area in the model), when compared to the corner of the table on which the cup is located. In the present model, such specific value would concern the stimuli of interest and the position they occupy in space. Therefore, this layer would allow the system to create a perceptual map of the surrounding space, where salient stimuli and space are endowed with a certain value and perceptual priority. We could imagine that in patients presenting unilateral spatial neglect (i.e., a brain lesion-derived neurological disorder inducing a reduction of the attention to and awareness of the hemispace opposite to the damaged brain hemisphere; Heilman et al., 1987), the neglected hemispace could be excluded from such perceptual priority map.

The second layer corresponds to the *motor priority map* of near-body space. Similarly to the perceptual map, the motor map would be composed of multiple response-fields. Nevertheless, there would be one main difference: Value attribution to each field would be motor in nature. In other terms, this motor map would code the near-body space as a function of the potential actions that can be prioritised and realised in different portions of space. For this reason, this layer would underlie the action selection process. The motor priority map would be constructed on the basis of the body part mobilised

**Figure 11.1**
*A Model Accounting for PPS Construction*



*Note.* According to the present model, PPS construction would occur at three layers: a *perceptual priority map* layer, a *motor priority map* layer and a *motor action execution* layer. The three layers would be differently influenced by different factors, but they would not be independent. They would rather be interconnected and influence mutually, constituting a sort of sensorimotor loop constantly updating in order to allow the individual to respond with a proper behaviour to the demands of the task and the environment.

during the action as well as on the location of objects with respect to such body part. To illustrate this concept, we can take the example of right-handed individuals. For such individuals, the motor priority map would be heterogeneous across their near-body space and encompass to a larger extent the right vs. the left space. Due to right-hand preference, the right space corresponds to the space mainly used during daily actions, and therefore, were actions are more likely to be performed (see also the concept of motor fluency, e.g., more fluid actions are the ones carried out by the dominant hand on the dominant side; Milhau et al., 2015).

The third layer corresponds to the stage of motor action execution. We can speculate that motor commands are programmed at this stage in order to be sent to the relevant body effector. We could consider that this is the stage associated with what Cisek and Kalaska (2010) defined as the “action specification” process, namely “the process of specifying the spatio-temporal aspects of possible actions” (Cisek & Kalaska, 2010, p. 227). This latter layer would depend on the perceptual and motor priority map levels. The next section will describe more in detail how the three layers influence each other.

### 11.1.2 *The interconnection between the three layers and the factors influencing it*

Although the illustration shows the three layers as being separated, it is important to note that they can not be considered as independent, nor as being activated in a sequential order. In my conception, the three layers overlap, as indicated by the fact that they are vertically superposed, and they mutually influence each other, as indicated by the ascending and descending arrows. The construction of one layer would subtend the construction of the others, and a modification of the one would result in an adaptation of the others. Such parallel involvement of the three layers was inspired by the hypothesis advanced by Cisek on the basis of neurophysiological studies review, stating that sensory processing, action selection and action specification occur simultaneously and operate in a coordinate and integrated manner (Cisek & Kalaska, 2010).

Another feature of the present model is that the three layers would not be stable, but rather constructed instantaneously (as suggested by Bufacchi & Iannetti, 2019) as a function of the task demands, the stimulus/object, the eventual social context and various other factors. The findings emerging from the present research work support such multi-factors determined construction of PPS. The construction of PPS as a function of different factors could be resumed by the following metaphorical mathematical equation (Formula 11.1).

$$\begin{aligned} PPS_{(t)} = {} & ConstantFactors + (w_1 \times Task_{(t)}) + (w_2 \times MotorFactors_{(t)}) + \\ & (w_3 \times SocialContext_{(t)}) + (w_4 \times StimuliFeatures_{(t)}) + \ldots + \varepsilon \end{aligned} \tag{11.1}$$

Such equation states that PPS at an instant in time $t$ would be determined by (a) a constant term, (b) a series of parameters, each one associated with a given weight ($w$) and (c) an error term ($\varepsilon$). In this formula, $t$ indicates that the features of the concerned element vary according to the context and that are thereby determined in a specific instant in time. The constant would correspond to a series of factors that are stable in time, such as for instance the multisensory mechanism, arm length and body schema. All these factors would be specific to each individual and can be considered as a set of “tools” underlying PPS construction.

The parameters would correspond to all the factors that can vary during the interaction with the environment. Amongst them are the social context (e.g., the presence of another individual, the execution of a collaborative task or a joint action with a confederate, etc.), the features of the object/stimulus (e.g., a small or big glass, a computer mouse vs. a keyboard), the type of task (e.g., grasping, reaching), motor action-related factors (e.g., reward prospects, features of the final spatial target...), but also the previous motor experience in space.

The weight $w$ associated with each parameter would depend on the characteristics of situation in a given time and space. Positive ($+w$) or negative ($-w$) weights values would determine respectively approach or avoidance behaviours towards a given portion of space. As an example, we can evoke the results of the present thesis. Let’s consider the situation where individuals perform the stimuli-selection task in collaboration with a confederate, and action reward prospects are higher in the confederate's PPS). In such a case, the weight associated with the motor factors parameter (indicating rewards prospects in the far space) could have the value of 5 (such value is arbitrarily attributed for the sake of the example). Nevertheless, since the distal space corresponds to the confederate's PPS and that individual tends to avoid it, we could speculate that the weight associated with the social context would be -10, as invading other space has stronger consequences on one's own behaviour and personal integrity. Therefore, the combination of weights for such portion of space being negative (i.e., -5), individuals would tend to avoid selecting the stimuli located in confederate's PPS, ant therefore avoid acting within it. On the contrary, in a situation where individuals perform the same task but alone, as in Coello et al. (2018), the weight associated with the social context would be equal to 0. As a consequence, reward prospects would be the main factors determining PPS perceptual and motor priority maps, and consequently motor behaviour in space.

The error term ($\varepsilon$) would allow to take into account the potential influence of other factors not accounted in the construction of PPS (e.g., individual characteristics such as anxiety or other psychopathological traits, prosocial attitude...), but that could be considered in future interactions with the environment.

The components specified in Formula 11.1 (constant, parameters and their weights and error term) can exert an influence on all the three layers of the model. When considering the findings of the present thesis, we could state that rewards associated with self-generated motor actions influence the motor priority map and action execution layers, and as a consequence, remap the perceptual priority map layer. On the contrary, observing other's action rewards (which would therefore correspond to the other's motor execution layer) seems sufficient enough to modify the observer's perceptual priority map, but not the motor priority map layer. The social intention would impact concurrently the three layers: I am sensitive to and take into account other's PPS (eventually merging my own PPS with others'), I chose where to act in space, and the spatio-temporal properties of my actions are modified by the intention to include the other person in the interaction. The arguments provided above suggest that PPS construction depends on the influence of a given set of factors tightly linked to the specific moment in time and space. However, one question arises now logically: What is the exact nature of PPS?

### 11.1.3 *An a priori or an on-line construction?*

If we consider that PPS is constantly adjusted as a function to the constraints in time and space, one might wonder what is the exact nature of PPS: Is it a stable representation that constantly adapts to the constraints of the context, or is it rather an instantaneous map of space that is computed and constructed instant by instant as a function of the integration of these constrains? In both cases, one could argue that it would not be economic for the system. The idea of a stable representation would not be parsimonious, since one might wonder what is the utility of having a stable representation that needs constant adjustments in order to be functional to the individual's needs. Such constant adjustments would be too costly in terms of energy. Furthermore, empirical data fail at supporting such conception, since the idea of a stable representation of the world constructed by the brain does not complies with the constant modulation of neuronal activity by attention orientation in space (Cisek & Kalaska, 2010). However, on the other side, one might consider that computing all the time the value attributed to a given portion of space would not be parsimonious either. Such constant computation from a *tabula rasa* would require a certain amount of constant energy. Furthermore, such conceptualisation would contradict the existence of anticipatory and predictive mechanisms, which have been found to play a crucial role in the optimisation of the external world processing (see Kawato et al., 1987; Miall & Wolpert, 1996; Wolpert et al., 2003).

A way to solve this issue could rely on the consideration that the brain retains a sort of "embryonic" semi-stable representation of PPS, that would serve as a basis for the construction of the "instantaneous" multiple-field spatial map in a given space and time. Such embryonic semi-stable representation would be plastic (i.e., slowly changing following learning, training or cortex lesions) but not dynamic (i.e., changing abruptly following as change in the environment or the individual's internal state; definitions provided by Cléry et al., 2015).

In a broader prospective, such debate about the a priori vs. on-line construction of PPS mirrors the cognitivism vs. enactivism current of thought of human cognition (see Versace et al., 2018). According to cognitivism, the individual needs a representation of the surrounding environment and its elements. The reference is in the external world and the brain has to build a representation in order to apprehend it. Due to this representation, the brain would then program the most pertinent actions to be executed in the environment. On the contrary, according to enactivism, the system does not need any prior representation of the surrounding environment and its elements. The reality is not pre-existent but co-constructed by the organism through a sensori-motor mechanisms occurring during the direct experience of the individual with the environment. The reference would thereby correspond to the sensori-motor approach of external stimuli. The truth[1] lies in the middle, which is represented by the embodied and situated approach of cognition (for a review, see Borghi & Cimatti, 2010; Coello & Fischer, 2016; Versace et al., 2018). According to such approach, the system would build a representation of the external world, but this representation would not have the role to process the information (input) in order to produce an action (output). It would directly serve the action, and would thereby be sensori-motor in nature.

The model proposed can be placed within this context, with the idea that PPS construction is embodied. The three maps composing the PPS construction model would

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[1] The reader would pardon me for such an abuse of language, which is here at the service of the fluidity and language style for the argumentation rather than to affirm an universal truth, which would be epistemologically incorrect.

be separated but still tightly and bidirectionally linked, with constant adaptations of each layer subserving a functional, sensori-motor construction of PPS.

## 11.2 GENERAL CONCLUSIONS

### 11.2.1 *Limitations*

The present research work presents several limitations that are worthy of note. A first limitation is that PPS construction was assessed when placing participants in front of each other. The consequence of such a spatial disposition is that if individuals intend to act in the space of their confederate, they are induced to enter others' space directly from the front. Such motor behaviour could have been perceived as a "stronger invasion" than what would have happened if participants had sat side by side. Future studies are needed in order to exhaustively explore how individuals organise their actions in space as a function of the spatial proximity and location of a confederate.

Another important limitation concerns the absence of significant effects for some studies. In the context of the present thesis, I made the choice to adopt the frequentist approach. Nevertheless, making assumptions only on the basis of a cut-off is quite reductive and does not allow to deeply understand the effect of the manipulated factors. No clear-cut conclusions are possible on the basis of non-significant results, except affirming that we can not firmly conclude about a given phenomenon. The hypotheses and explanations advanced in the present thesis could be strengthened by analysing data using a Bayesian approach (e.g., for mixed models), which would allow to assess whether the effect is truly absent or not (Lakens et al., 2020).

In addition, it is worth noting that PPS representation was assessed by means of an explicit task (i.e., the reachability judgment task) recruiting sensori-motor processes through motor imagery (see Geers et al., 2021; Pelgrims et al., 2011), relying on motor imagery, a relatively high-level process that recruits sensori-motor , such as y. It would be therefore be interesting to replicate the present experiments using more implicit tasks, such as the multisensory integration task. The use of this implicit task would also allow to shed light on the exact interplay between sensorial and motor coding of space, and determine to what extent low-level mechanisms are impacted by similar factors than higher-level processes when constructing PPS.

A final limitation in the present research work concerns the interpretation of the effect of observing other's action rewards on PPS construction. The limitation resides in the fact that it is difficult to disentangle whether the increase of PPS representation induced by other's rewards was due to a form of sensitiveness to others' actions, or simply by a learning of the statistical regularities of the environment. Said differently, one could wonder whether a similar extension effect had been observed if a robotic arm would have performed the stimuli-selection task. Therefore, whether we sensitive to others' action (and rewards) or simply to the statistical regularities events of the environment remains an open issue.

### 11.2.2 *Future perspectives*

The present thesis paves the way for several new theoretical avenues and potential applications. A natural progression of this work would be to analyse how exactly the different factors influencing PPS contribute to its construction. In the present thesis, PPS was conceptualised as a multi-response field, each field being endowed a given value. I advanced the idea that multiple factors would concurrently be integrated to determine such value. Nevertheless, the way these factors interact need further clarifications: Do they exert an additive effect on each other? Do they rather interact among each other and then influence PPS construction?

Moreover, the empirical findings, theoretical hypotheses and functional model proposed in the present thesis provide several insights for future researches in the field of clinical psychology. For instance, they might offer a new framework allowing the examination of social deficits in autism and schizophrenia spectrum disorders. Indeed, several studies have recently highlighted in such populations an impairment of the multisensory integration, body frontiers processing as well as PPS coding (e.g., Delevoye-Turrell et al., 2011; Ferroni et al., 2020; Mul et al., 2019). In light of these findings, it would be pertinent to test whether the impaired multisensory integration underlying body frontiers and PPS would explain the difficulties in social interactions (whether it is interpersonal distance regulation or action execution in space) classically observed in such pathologies (e.g., Kennedy & Adolphs, 2014; Park et al., 2009) Finally, more studies will need to be conducted to determine to what extent others' actions influence the way individuals apprehend the world. The findings of the present thesis suggested that other's action might influence PPS representation. Such result might find an explanation in the recruitment of mirror mechanisms, as suggested by previous literature (e.g., Fujii et al., 2007; Livi et al., 2019; Pezzulo & Dindo, 2011). Nevertheless, they also suggest that mirror mechanisms might not be recruited during action selection and that one's own motor experience would be needed to actually construct a motor priority map of space. More broadly, these findings might therefore provide new insights to understand imitation processes and learning by observing other agents.

### 11.2.3 *Contributions of the present thesis*

As a first main contribution, the present body of work enlarges the conceptualisation of PPS proposed by Bufacchi and Iannetti (2018, 2019) as a multiple motor response-fields zone. Specifically, the present thesis showed that, in addition to stimuli value and past motor experiences, motor- and social context-related factors contribute to the attribution of a functional value to a given portion of space, determining whether and how exploiting such portion of space. In addition, the present findings provide empirical evidence for a bidirectional modulation between social and motor factors on the attribution of such action-related value.

The second contribution of the present thesis was the examination of two dimensions when assessing the influence of motor and social factors on PPS, namely the way individuals represent such space (i.e., PPS representation) and use it during their interaction with the physical and social environment (i.e., PPS exploitation). Results showed that these two dimensions, despite being interconnected and determining each other, would be differently influenced by the factors manipulated. The examination of these two dimensions was a novelty with respect to the existent literature and the findings of the present thesis strongly suggest that both dimensions need to be taken into account in further studies in order to properly examine PPS.

A final contribution of the present thesis was the consideration of PPS as a space not only underlying the interaction with the physical environment, but also structuring (and being structured by) social interactions. Accordingly, results revealed that social interactions are grounded and embedded in a physical and motor context, which determines the way individuals move in space to communicate non-verbally with other individuals.

In conclusion, the present PhD thesis proposes a functional conception of PPS. Specifically, it defends the idea that PPS construction is not stable, but constructed in a specific instant as a function of the task demands, stimuli features and the physical and social context. The integration of such factors influences individuals' PPS representation and exploitation, determining therefore whether and how individuals prioritise a given portion of space during their interactions with the environment.

# Part IV

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# BIBLIOGRAPHY

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# Part V

# APPENDICES

# A

# ETHICAL CLEARANCE

## STUDY 1, IN CHAPTER 5

Université de Lille

### Comité d'éthique en sciences comportementales

Président :
Yvonne DELEVOYE-TURRELL

Président adjoint :
Céline DOUILLIEZ

Personne ressource (dossier administratif) :
Aurélie DUCROQUET
Tél : 03.20.41.67.92 -
E-mail : aurelie.ducroquet@univ-lille3.fr

Villeneuve d'Ascq le 15/12/2017

**Références comité d'éthique :** **2017-7-S52**
**Sigle :** **PEPS**
**Numéro de version et date :** **Version 2 du 29/06/17**
**Promoteur :** **Lille 3**
**Porteur projet :** **Yann Coello**

**Date de la soumission :** **07/06/2017**
**Date de la réunion du comité d'éthique :** **08/06/2017**
**Avis du comité d'éthique :** **AVIS FAVORABLE**

*Le protocole est accepté en état. Si pour une quelconque raison, vous souhaitez modifier le protocole (en terme de calendrier, inclusion d'un nouveau groupe…), vous êtes tenu d'informer le comité d'éthique par l'envoi d'un avenant expliquant les motivations mais également les modifications apportées au protocole initial.*
*Cet avenant sera réévalué par le comité d'éthique.*

Pr Yvonne DELEVOYE-TURRELL
Présidente du comité d'éthique
Y. Delevoye

Page 1 sur 1

## STUDY 2, IN CHAPTER 6

Université de Lille

### Comité d'éthique en sciences comportementales

Président :
Yvonne DELEVOYE-TURRELL

Président adjoint :
Cédric PATIN

Responsable administrative :
Stella BOUAMRIRENE
Tel : 03 -62- 26- 80- 82
E-mail : Stella.Bouamrirene@univ-Lille.fr

Villeneuve d'Ascq le 20/11/2019

| | |
|---|---|
| **Références comité d'éthique :** | 2019-374-S77 |
| **Sigle :** | **REPS-OA** |
| **Numéro de version et date :** | **Version 2 du 15/11/2019** |
| **Promoteur :** | **ULille SHS** |
| **Responsable Scientifique du projet :** | **Yann COELLO** |

**Date de la soumission :**

**Avis du Comité d'Ethique : Avis favorable.**

*Le protocole est accepté en état. Si pour une quelconque raison, vous souhaitez modifier le protocole (en terme de calendrier, inclusion d'un nouveau groupe…), vous êtes tenu d'informer le comité d'éthique par l'envoi d'un avenant expliquant les motivations mais également les modifications apportées au protocole initial.*

*Cet avenant sera réévalué par le comité d'éthique.*

*L'avis du CER-Lille n'exonère pas des formalités réglementaires. A cet égard, il vous appartient notamment, si vous traitez des données se rapportant à un individu directement ou indirectement identifiable, de vous conformer au règlement européen sur la protection des données (RGPD) en vigueur depuis 2018. Pour cela, vous pouvez solliciter les conseils du Correspondant informatique et libertés (DPO) ou du service juridique de votre université ou de votre organisme de recherche.*

Pr Yvonne DELEVOYE-TURRELL
Présidente du comité d'éthique

Y. Delevoye

Page 1 sur 1

## STUDY 3, IN CHAPTER 7

Université de Lille

## Comité d'éthique en sciences comportementales

Président :
Yvonne DELEVOYE-TURRELL

Président adjoint :
Cédric PATIN

Responsable administrative :
Stella BOUAMRIRENE
Tel : 03 -62- 26- 80- 82
E-mail : Stella.Bouamrirene@univ-Lille.fr

Villeneuve d'Ascq le 11/10/2019

| | |
|---|---|
| **Références comité d'éthique :** | 2019-363-S75 |
| **Sigle :** | **EISEOM** |
| **Numéro de version et date :** | **Version 3 du 10/10/2019** |
| **Promoteur :** | **ULille SHS** |
| **Responsable Scientifique du projet :** | **Yann COELLO** |

**Date de la soumission : 11/10/2019**

**Avis du Comité d'Ethique : Avis favorable.**

*Le protocole est accepté en état. Si pour une quelconque raison, vous souhaitez modifier le protocole (en terme de calendrier, inclusion d'un nouveau groupe…), vous êtes tenu d'informer le comité d'éthique par l'envoi d'un avenant expliquant les motivations mais également les modifications apportées au protocole initial.*

*Cet avenant sera réévalué par le comité d'éthique.*

*L'avis du CER-Lille n'exonère pas des formalités réglementaires. A cet égard, il vous appartient notamment, si vous traitez des données se rapportant à un individu directement ou indirectement identifiable, de vous conformer au règlement européen sur la protection des données (RGPD) en vigueur depuis 2018. Pour cela, vous pouvez solliciter les conseils du Correspondant informatique et libertés (CIL) ou du service juridique de votre université ou de votre organisme de recherche.*

Pr Yvonne DELEVOYE-TURRELL
Présidente du comité d'éthique

Y. Delevoye

Page 1 sur 1

## STUDY 4, IN CHAPTER 8

Université de Lille

### Comité d'éthique en sciences comportementales

Présidente :
Yvonne DELEVOYE-TURRELL

Président adjoint :
Cédric PATIN

Gestionnaire administrative :
Stella BOUAMRIRENE
Tel : 03 -62- 26- 80- 82
E-mail : Stella.Bouamrirene@univ-Lille.fr

Villeneuve d'Ascq, le 17/11/2020

**Références comité d'éthique :** **2020-437-S86**

**Sigle :** **ERDER**

**Numéro de version et date :** **Version 2 du 02/11/2020**

**Promoteur :** **ULILLE-SHS-ALL**

**Responsable Scientifique du projet : Yann COELLO**

**Date de la soumission : 02/11/2020**

**Date de la réunion du comité d'éthique : 16/11/2020**

Avis du Comité d'Ethique : Avis favorable

*Le protocole est accepté en état. Si pour une quelconque raison, vous souhaitez modifier le protocole (en terme de calendrier, inclusion d'un nouveau groupe…), vous êtes tenu d'informer le comité d'éthique par l'envoi d'un avenant expliquant les motivations mais également les modifications apportées au protocole initial. Cet avenant sera réévalué par le comité d'éthique.*

*L'avis du CER-Lille n'exonère pas des formalités réglementaires. A cet égard, il vous appartient notamment, si vous traitez des données se rapportant à un individu directement ou indirectement identifiable, de vous conformer au règlement européen sur la protection des données (RGPD) en vigueur depuis 2018. Pour cela, vous pouvez solliciter les conseils du Correspondant informatique et libertés (DPO) ou du service juridique de votre université ou de votre organisme de recherche. Le comité éthique rappelle l'obligation d'inscrire au registre des traitements de l'université tout traitement de données à caractère personnel conformément à l'article 30 du Règlement Général sur la Protection des données.*

*Par cet avis favorable, le CER U-Lille ne se prononce pas sur le respect des mesures barrières contre le Covid-19. Afin de protéger les participants et les chercheurs et enseignants-chercheurs, les organismes responsables de la recherche doivent impérativement se mettre en conformité avec les mesures préconisées pour toutes recherches sur site et hors site par les tutelles hébergeant les unités de recherche concernées.*

Pr Yvonne DELEVOYE-TURRELL
Présidente du comité d'éthique
Y. Delevoye

**DAR - Direction de l'Appui à la Recherche**
Service Pilotage des Partenariats, des Structures de Recherche et des Plateformes
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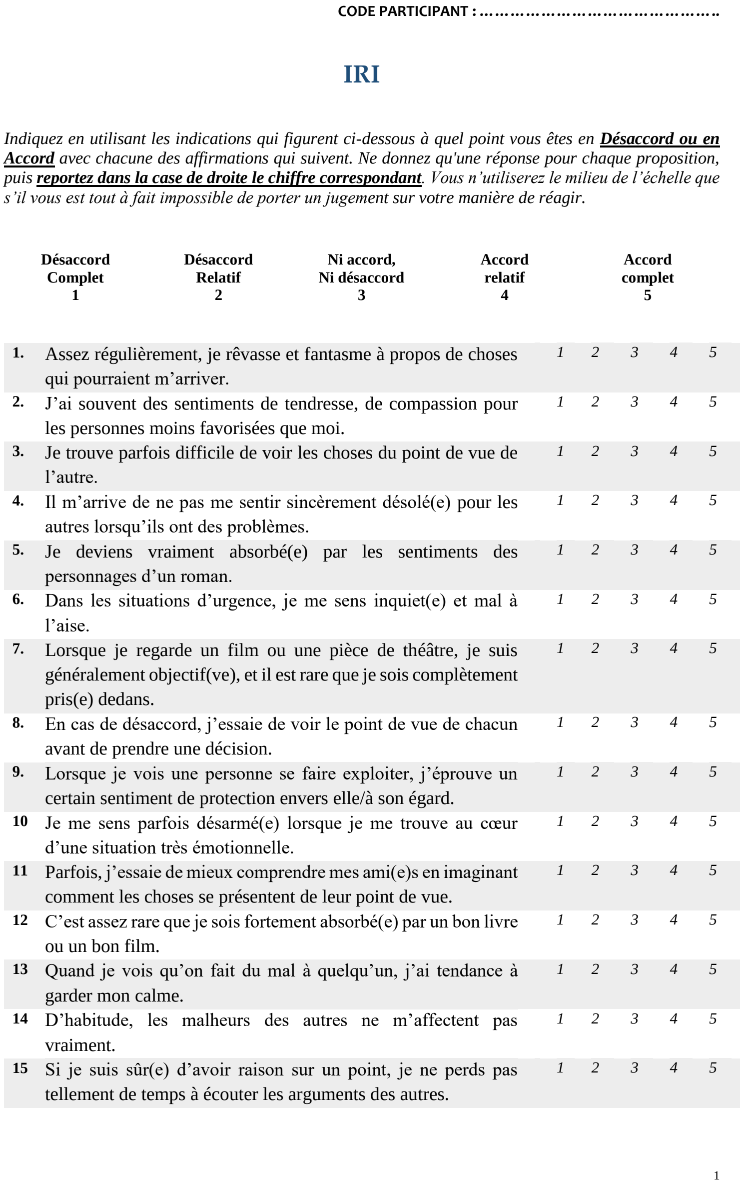
# B

# SOCIAL CHARACTERISTICS QUESTIONNAIRES

## INTERPERSONAL REACTIVITY INDEX (IRI)-CHAPTER 5



CODE PARTICIPANT : ……………………………………………

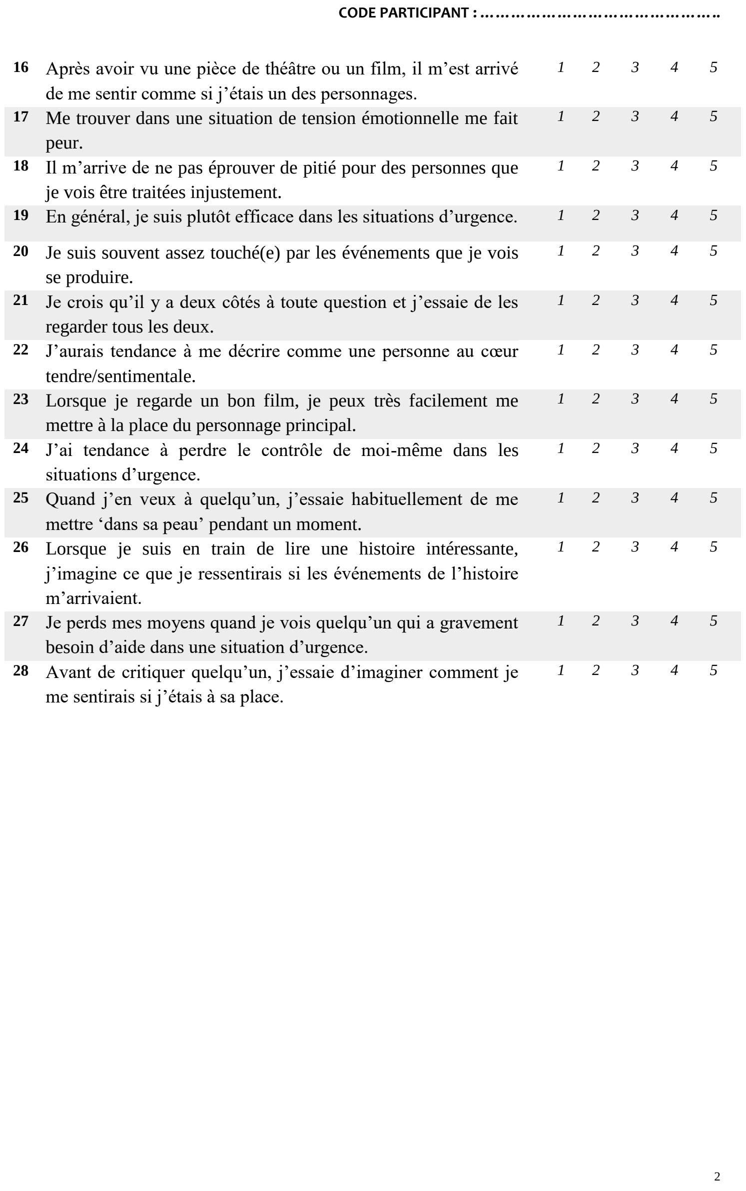
### IRI

*Indiquez en utilisant les indications qui figurent ci-dessous à quel point vous êtes en* ***Désaccord ou en Accord*** *avec chacune des affirmations qui suivent. Ne donnez qu'une réponse pour chaque proposition, puis* ***reportez dans la case de droite le chiffre correspondant****. Vous n'utiliserez le milieu de l'échelle que s'il vous est tout à fait impossible de porter un jugement sur votre manière de réagir.*

| Désaccord Complet 1 | Désaccord Relatif 2 | Ni accord, Ni désaccord 3 | Accord relatif 4 | Accord complet 5 |
|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| **1.** | Assez régulièrement, je rêvasse et fantasme à propos de choses qui pourraient m'arriver. | *1* | *2* | *3* | *4* | *5* |
| **2.** | J'ai souvent des sentiments de tendresse, de compassion pour les personnes moins favorisées que moi. | *1* | *2* | *3* | *4* | *5* |
| **3.** | Je trouve parfois difficile de voir les choses du point de vue de l'autre. | *1* | *2* | *3* | *4* | *5* |
| **4.** | Il m'arrive de ne pas me sentir sincèrement désolé(e) pour les autres lorsqu'ils ont des problèmes. | *1* | *2* | *3* | *4* | *5* |
| **5.** | Je deviens vraiment absorbé(e) par les sentiments des personnages d'un roman. | *1* | *2* | *3* | *4* | *5* |
| **6.** | Dans les situations d'urgence, je me sens inquiet(e) et mal à l'aise. | *1* | *2* | *3* | *4* | *5* |
| **7.** | Lorsque je regarde un film ou une pièce de théâtre, je suis généralement objectif(ve), et il est rare que je sois complètement pris(e) dedans. | *1* | *2* | *3* | *4* | *5* |
| **8.** | En cas de désaccord, j'essaie de voir le point de vue de chacun avant de prendre une décision. | *1* | *2* | *3* | *4* | *5* |
| **9.** | Lorsque je vois une personne se faire exploiter, j'éprouve un certain sentiment de protection envers elle/à son égard. | *1* | *2* | *3* | *4* | *5* |
| **10** | Je me sens parfois désarmé(e) lorsque je me trouve au cœur d'une situation très émotionnelle. | *1* | *2* | *3* | *4* | *5* |
| **11** | Parfois, j'essaie de mieux comprendre mes ami(e)s en imaginant comment les choses se présentent de leur point de vue. | *1* | *2* | *3* | *4* | *5* |
| **12** | C'est assez rare que je sois fortement absorbé(e) par un bon livre ou un bon film. | *1* | *2* | *3* | *4* | *5* |
| **13** | Quand je vois qu'on fait du mal à quelqu'un, j'ai tendance à garder mon calme. | *1* | *2* | *3* | *4* | *5* |
| **14** | D'habitude, les malheurs des autres ne m'affectent pas vraiment. | *1* | *2* | *3* | *4* | *5* |
| **15** | Si je suis sûr(e) d'avoir raison sur un point, je ne perds pas tellement de temps à écouter les arguments des autres. | *1* | *2* | *3* | *4* | *5* |

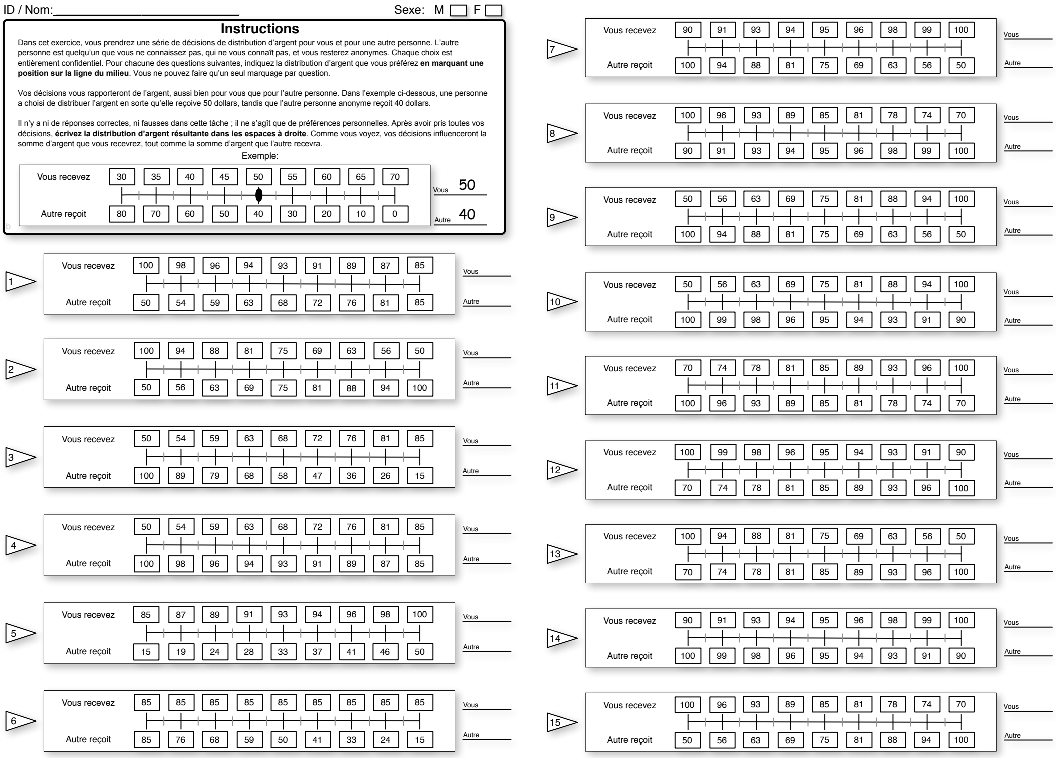
1



**CODE PARTICIPANT : ……………………………………………..**

| | | | | | | |
|---|---|---|---|---|---|---|
| **16** | Après avoir vu une pièce de théâtre ou un film, il m'est arrivé de me sentir comme si j'étais un des personnages. | *1* | *2* | *3* | *4* | *5* |
| **17** | Me trouver dans une situation de tension émotionnelle me fait peur. | *1* | *2* | *3* | *4* | *5* |
| **18** | Il m'arrive de ne pas éprouver de pitié pour des personnes que je vois être traitées injustement. | *1* | *2* | *3* | *4* | *5* |
| **19** | En général, je suis plutôt efficace dans les situations d'urgence. | *1* | *2* | *3* | *4* | *5* |
| **20** | Je suis souvent assez touché(e) par les événements que je vois se produire. | *1* | *2* | *3* | *4* | *5* |
| **21** | Je crois qu'il y a deux côtés à toute question et j'essaie de les regarder tous les deux. | *1* | *2* | *3* | *4* | *5* |
| **22** | J'aurais tendance à me décrire comme une personne au cœur tendre/sentimentale. | *1* | *2* | *3* | *4* | *5* |
| **23** | Lorsque je regarde un bon film, je peux très facilement me mettre à la place du personnage principal. | *1* | *2* | *3* | *4* | *5* |
| **24** | J'ai tendance à perdre le contrôle de moi-même dans les situations d'urgence. | *1* | *2* | *3* | *4* | *5* |
| **25** | Quand j'en veux à quelqu'un, j'essaie habituellement de me mettre 'dans sa peau' pendant un moment. | *1* | *2* | *3* | *4* | *5* |
| **26** | Lorsque je suis en train de lire une histoire intéressante, j'imagine ce que je ressentirais si les événements de l'histoire m'arrivaient. | *1* | *2* | *3* | *4* | *5* |
| **27** | Je perds mes moyens quand je vois quelqu'un qui a gravement besoin d'aide dans une situation d'urgence. | *1* | *2* | *3* | *4* | *5* |
| **28** | Avant de critiquer quelqu'un, j'essaie d'imaginer comment je me sentirais si j'étais à sa place. | *1* | *2* | *3* | *4* | *5* |

## SOCIAL VALUE ORIENTATION (SVO) SLIDER MEASURE-CHAPTER 5



ID / Nom:____________________________ Sexe: M ☐ F ☐

**Instructions**

Dans cet exercice, vous prendrez une série de décisions de distribution d'argent pour vous et pour une autre personne. L'autre personne est quelqu'un que vous ne connaissez pas, qui ne vous connaît pas, et vous resterez anonymes. Chaque choix est entièrement confidentiel. Pour chacune des questions suivantes, indiquez la distribution d'argent que vous préférez **en marquant une position sur la ligne du milieu**. Vous ne pouvez faire qu'un seul marquage par question.

Vos décisions vous rapporteront de l'argent, aussi bien pour vous que pour l'autre personne. Dans l'exemple ci-dessous, une personne a choisi de distribuer l'argent en sorte qu'elle reçoive 50 dollars, tandis que l'autre personne anonyme reçoit 40 dollars.

Il n'y a ni de réponses correctes, ni fausses dans cette tâche ; il ne s'agît que de préférences personnelles. Après avoir pris toutes vos décisions, **écrivez la distribution d'argent résultante dans les espaces à droite**. Comme vous voyez, vos décisions influenceront la somme d'argent que vous recevrez, tout comme la somme d'argent que l'autre recevra.

Exemple:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | Vous 50 |
| Autre reçoit | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0 | Autre 40 |

1

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 100 | 98 | 96 | 94 | 93 | 91 | 89 | 87 | 85 | Vous ______ |
| Autre reçoit | 50 | 54 | 59 | 63 | 68 | 72 | 76 | 81 | 85 | Autre ______ |

2

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 100 | 94 | 88 | 81 | 75 | 69 | 63 | 56 | 50 | Vous ______ |
| Autre reçoit | 50 | 56 | 63 | 69 | 75 | 81 | 88 | 94 | 100 | Autre ______ |

3

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 50 | 54 | 59 | 63 | 68 | 72 | 76 | 81 | 85 | Vous ______ |
| Autre reçoit | 100 | 89 | 79 | 68 | 58 | 47 | 36 | 26 | 15 | Autre ______ |

4

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 50 | 54 | 59 | 63 | 68 | 72 | 76 | 81 | 85 | Vous ______ |
| Autre reçoit | 100 | 98 | 96 | 94 | 93 | 91 | 89 | 87 | 85 | Autre ______ |

5

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 85 | 87 | 89 | 91 | 93 | 94 | 96 | 98 | 100 | Vous ______ |
| Autre reçoit | 15 | 19 | 24 | 28 | 33 | 37 | 41 | 46 | 50 | Autre ______ |

6

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | Vous ______ |
| Autre reçoit | 85 | 76 | 68 | 59 | 50 | 41 | 33 | 24 | 15 | Autre ______ |

7

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 90 | 91 | 93 | 94 | 95 | 96 | 98 | 99 | 100 | Vous ______ |
| Autre reçoit | 100 | 94 | 88 | 81 | 75 | 69 | 63 | 56 | 50 | Autre ______ |

8

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 100 | 96 | 93 | 89 | 85 | 81 | 78 | 74 | 70 | Vous ______ |
| Autre reçoit | 90 | 91 | 93 | 94 | 95 | 96 | 98 | 99 | 100 | Autre ______ |

9

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 50 | 56 | 63 | 69 | 75 | 81 | 88 | 94 | 100 | Vous ______ |
| Autre reçoit | 100 | 94 | 88 | 81 | 75 | 69 | 63 | 56 | 50 | Autre ______ |

10

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 50 | 56 | 63 | 69 | 75 | 81 | 88 | 94 | 100 | Vous ______ |
| Autre reçoit | 100 | 99 | 98 | 96 | 95 | 94 | 93 | 91 | 90 | Autre ______ |

11

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 70 | 74 | 78 | 81 | 85 | 89 | 93 | 96 | 100 | Vous ______ |
| Autre reçoit | 100 | 96 | 93 | 89 | 85 | 81 | 78 | 74 | 70 | Autre ______ |

12

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 100 | 99 | 98 | 96 | 95 | 94 | 93 | 91 | 90 | Vous ______ |
| Autre reçoit | 70 | 74 | 78 | 81 | 85 | 89 | 93 | 96 | 100 | Autre ______ |

13

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 100 | 94 | 88 | 81 | 75 | 69 | 63 | 56 | 50 | Vous ______ |
| Autre reçoit | 70 | 74 | 78 | 81 | 85 | 89 | 93 | 96 | 100 | Autre ______ |

14

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 90 | 91 | 93 | 94 | 95 | 96 | 98 | 99 | 100 | Vous ______ |
| Autre reçoit | 100 | 99 | 98 | 96 | 95 | 94 | 93 | 91 | 90 | Autre ______ |

15

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Vous recevez | 100 | 96 | 93 | 89 | 85 | 81 | 78 | 74 | 70 | Vous ______ |
| Autre reçoit | 50 | 56 | 63 | 69 | 75 | 81 | 88 | 94 | 100 | Autre ______ |

# C

# CURRICULUM VITAE

## Maria Francesca Gigliotti

**DOCTORANTE EN PSYCHOLOGIE et**
**PSYCHOLOGUE SPECIALISEE EN NEUROPSYCHOLOGIE**

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07 81 53 64 39
mariaf.gigliotti@gmail.com
/ maria-francesca-gigliotti-19133710b /

### FORMATION

2018- en cours // **Doctorat en Psychologie Cognitive.** Thèse réalisée sous la direction du Pr. Yann Coello et du Pr. Angela Bartolo.

- **InDOC (2 mois)** au sein du Laboratoire de Neuropsychophysiologie (Université do Minho, Portugal), supervisé par le Pr. Adriana SAMPAIO, financé par l'I-Site Ulne.

2017-2018 // **Master 2 Européen Psychologie des Processus Neuro-cognitifs et Sciences Affectives**, *Mention Très Bien*, Université de Lille 3, France. Intitulé du Travail d'Etudes et de Recherche : « *Perceiving and acting in a common and shared space : an exploration of the social dimension of peri-personal space* ». Travail dirigé par le Pr. Yann Coello.

2016-2017 // **Master 1 de Psychologie,** *Mention Très Bien,* Université de Lille 3, France. Intitulé du Travail d'Etudes et de Recherche : « *Effet des conséquences des actions dans l'environnement et du contexte social sur la représentation de l'espace péri-personnel.* Travail dirigé par le Pr. Yann Coello.

2013-2016 // **Licence de Psychologie,** *Mention Très Bien*, Université de Lille 3. Intitulé du Travail d'Etudes : « *Espace péri-personnel et conséquences des actions dans l'environnement : les feedbacks environnementaux modifient-ils la perception de notre espace d'action.* Travail dirigé par le Pr. Yann Coello et co-encadré par le Dr. François Quesque.

2009-2013 // **Diplôme de fin d'études,** *Mention Très Bien avec félicitations du jury*, Lycée Linguistique I.I.S. « Giovanna de Nobili ». Catanzaro, Italie

Octobre 2012 // **Cours Intensif d'Anglais** (3 semaines), Alpha College, Dublin, Irlande.

Juillet 2008 // **Cours Intensif d'Anglais** (2 semaines), Emerald Culture Institute, Dublin, Irlande.

### FORMATIONS COMPLEMENTAIRES

Février 2022/ **Formation « Initiation aux métiers du conseil ».** Organisée par l'Ecole Doctorale SHS, Université de Lille. Lille, France.

Mars 2021 // **Formation « Utiliser des Jeux Pédagogiques en ligne pour enseigner ».** Organisée par la Direction Innovation Pédagogique, Université de Lille. Lille, France.

Octobre – Decembre 2020 // **Formation "Teamwork Skills: Communicating Effectively in Groups».** Tenue par le Pr. Matthew Koschmann, (University of Colorado Boulder). Formation en ligne sur la plateforme Coursera.

### INFORMATIONS PERSONNELLES

**Age** : 28 ans
**Nationalité :** Italienne

### LANGUES

**Italien**
**Français**
**Anglais**
**Allemand**

### CERTIFICATIONS

**Delf B2,** Français, 2011
**TRINITY Grade 10,** Anglais, 2012
**FIT in Deutsch A2,** Allemand, 2012

## PUBLICATIONS ET COMMUNICATIONS SCIENTIFIQUES

### Publications Scientifiques

**Gigliotti, M.F.,** Sampaio, A., Bartolo, A., Coello, Y. (2020, Août). The combined effects of motor and social goals on the kinematics of object-directed motor action. *Scientific Reports, 10(1), 1-10.*

**Gigliotti, M.F**., Soares Coelho, P., Coutinho, J., & Coello, Y. (2019). Peripersonal space in social context is modulated by action reward, but differently in males and females. *Psychological Research,* 1-14.

Coello, Y., Quesque, F., **Gigliotti, M.F.,** Ott, L., & Bruyelle, J.L. (2018). Idiosyncratic representation of peripersonal space depends on the success of one's own motor actions, but also the successful actions of others! PLOS ONE 13(5): e0196874.

### Communication Orales

**Gigliotti, M.F.,** Ott, L., Bartolo, A. & Coello, Y. (2022, Ao). *The contribution of eye gaze and movement kinematics to the expression and the identification of social intention in object-directed motor actions*. ESCOP, Lille, France.

**Gigliotti, M.F.,** Bartolo, A. & Coello, Y. (2022, Juin). *Communicating our intentions to others through movement kinematics*. JSJC, Grenoble, France.

**Gigliotti, M.F.,** Desrosiers, P.A., Ott, L., Bartolo, A., & Coello, Y. (2020, Novembre). Do we behave in front of virtual agents as we would do in front of real people? : A kinematic study of the effect of social intentions on action execution. XVe Journée Scientifique des Jeunes Chercheurs en Psychologie, Lille, France.

Baillard, A. & **Gigliotti, M.F**. (2018, Octobre). Diagnostic et prise en charge de la cécité corticale : illustration de stratégies de rééducation inspirées des méthodes et des données de la recherche élaborées spécifiquement pour les cas des patients BE et LJ. CNNC, Amiens, France.

Coello, Y., **Gigliotti, M.F.,** Coelho, P., & Quesque, F. (2018, septembre). The social dimension of peripersonal space. ICSC, Rome, Italie.

**Gigliotti, M.F.**, Quesque, F., Ott, L., Bruyelle, J.L., & Coello, Y. (2017, Décembre). Influence de nos actions dans l'environnement et du contexte social sur la perception de l'espace péri-personnel. XIIe Journée Scientifique des Jeunes Chercheurs en Psychologie, Lille, France.

Coello, Y., Quesque, F., **Gigliotti, M.F.,** & Shemakova, E. (2017, Septembre). Effect of the positive-negative consequences of motor actions and the social context on the representation of peripersonal space. ESCOP, Potsdam, Allemagne.

### Communications Affichées

**Gigliotti, M.F**., Soares Coelho, P., Coutinho, & Coello, Y. (2019, Mars). The Social Dimension of Peripersonal Space: Action's reward and Gender effect on action space exploration and peripersonal space representation. ICPS, Paris, France.

**Gigliotti, M.F.**, & Coello, Y. (2018, Septembre). Perceiving and acting in a common and shared space: a systematic exploration of the social dimension of peri-personal space. ICSC, Rome, Italie.

**Gigliotti, M.F.**, Quesque, F**.**, Shemakova, E., & Coello, Y. (2017, Octobre). Effect of the positive-negative consequences of motor actions and the social context on the representation of peripersonal space. GDR Vision, Lille, France.

Coello Y., Quesque F., **Gigliotti M.F**., Shemakova E., Ott L., & Bruyelle J-L. (2017, Août). Consequences of motor actions and social context determine the representation of peripersonal space. ECVP, Berlin, Allemagne.

### Présentation orale durant des workshops

**Gigliotti, M.F**. (2019, novembre). Representation and exploration of peripersonal space as a function of action's reward and social context. *Cross-Border Vision of the Links Between Action and Cognition in Psychology*. Workshop organised by Michael ANDRES (Catholic University of Louvain-La-Neuve) and Solène KALENINE (University of Lille). Louvain-La-Neuve, Belgique.

## LOGICIELS MAITRISÉS

**Analyses Statistiques**
R, Statistica Jamovi, Jasp

**Programmation**
Matlab

**Traitement de texte**
LaTeX, Overleaf

**Logiciels pour la recherche en psychologie**
Limesurvey, Psychopy, E-prime

## DISTINCTIONS ET PRIX

**Bourse de mobilité internationale de recherche**
par l' I-Site Ulne
Bourse finançant un projet de recherche en neuroimagerie réalisé sous la supervision du Pr. Adriana SAMPAIO (Laboratoire de neuropsychophysiologie, Université du Minho), du Pr. Angela BARTOLO et du Pr. Yann COELLO (SCALab, Université de Lille)
Année 2020

**Ordre National des Excellences Italiennes**
Ministère de l'Instruction, de l'Université et de la Recherche Italien,
Année 2012-2013

**Excellence Scolaire de Calabre**
Fondazione Mediterranea Terina,
Région Calabre (Italie)
Année 2012

**Bourse au mérite**
ENPAPI,
Année 2013

**Bourse d'études AFS pour un mois d'étude en Finlande**
TelecomItalia S.p.a. AFS Intercultural Programs
Année 2010

### Responsabilités

2022// **Membre du Comité d'Organisation du congrès ESCOP-Lille 2022**

2020// **Vice-représentante des Doctorants, SCALab**

Depuis 2018 // **Membre du bureau de l'association PPNSA-Alumni.** Responsable de l'aide à l'organisation d'évènements.

16 mars 2018 // **Co-organisatrice de la 4$^{ème}$ Journée de Rencontre Praticiens-Chercheurs,** Tourcoing, France

## EXPÉRIENCES FORMATIVES ET PROFESSIONNELLES

Mai-Juin 2018 // **STAGE en Neuropsychologie en Soin de Suite et de Réadaptation** (Centre Hélène Borel, Raimbeaucourt). Bilans, rééducation cognitive auprès de patients adultes cérébro-lésés.

Février-Juin 2018 // **STAGE en Neuropsychologie en cabinet libéral** (Lille), encadré par Mme Coralie Becqueriaux. Bilan neuropsychologiques, Remédiation cognitive auprès d'enfants et jeunes adultes, psychoéducation, groupes de parole auprès d'enfants à haut potentiel intellectuel.

Janvier-Avril 2018 // **STAGE en Neuropsychologie en Service d'Addictologie** (CH Boulogne sur Mer). Diagnostic, compte-rendus, remédiation cognitive.

2017 // **STAGE en Neuropsychologie en cabinet libéral** (Lille), encadré par Mme Coralie Becqueriaux. Remédiation cognitive auprès d'enfants TDA-h, psychoéducation, groupes de parole pour les parents. Stimulation cognitive de groupe auprès de patients avec syndrome de Korsakoff.

2016-2017 // **STAGE en Neuropsychologie de l'enfant et de l'adolescent, Réseau NEURODEV** (Lille et CH Cambrai). Réalisation de bilans en HDJ (Service de Pédiatrie), élaboration de diagnostic, rédaction de compte-rendu, participation aux réunions pluridisciplinaires et accompagnement dans le travail de réseau.

2015 // **STAGE d'observation en EHPAD** (Madonna di Porto, Gimigliano, Italie). Entretiens avec le patient et la famille, anamnèse et évaluation cognitive globale, atelier de stimulation de mémoire autobiographique, thérapie par la réalité (ROT).

## EXPÉRIENCES ASSOCIATIVES ET PERSONNELLES

2007-2014 // **Membre de l'Association Musicale et Culturelle Serrastretta Joyful Chorus »** (Serrastretta, Italie).
Parmi les membres fondateurs. Concerts au niveau régional et national, organisation d'événements musicaux et culturels en collaboration avec d'autres chorales et orchestres, animation de mariages, participation à workshops de chant et direction chorale.

2011 // **Bénévole occasionnelle d'AFS - VIVRE SANS FRONTIERES (Italie)**
Témoignage et présentation des programmes d'échange. Assistance lors de la sélection des candidats. Préparation collective au départ des jeunes.

Août 2010 // **Programme d'échange interculturel en Finlande (Helsinki)**
Organisé par AFS Vivre sans Frontières. Expérience d'échange avec une famille d'accueil finlandaise, participation à un cours d'anglais de 3 semaines.

Depuis 2000 // **Étude de Danse** Classique /Contemporaine.

# COLOPHON

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[1] https://www.texstudio.org

[2] https://github.com/bashimao/ltu-thesis

[3] https://bitbucket.org/amiede/classicthesis

[4] https://tug.org/texlive

[5] https://linuxmint.com

[6] https://www.gnu.org/software/octave

[7] https://www.libreoffice.org

[8] https://www.gimp.org

[9] https://inkscape.org

[10] https://www.mendeley.com