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Postgraduate (Master's) Dissertation

The Role of Inhibition of Irrelevant Sources of Association in Detecting Action Affordances Between Objects

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Summary

The surrounding environment is full of entities which can be associated with each other, either due to some common characteristics, creating taxonomic relations, or because of a common thematic connection. According to the classical view of cognition, semantic memory is the store which holds all this information in an abstract, amodal form. Complementary to it, embodied cognition suggests that cognitive relations and cognition are not amodal, but they have modalities which are influenced by current events, the sociopolitical environment and the way one interacts with the world. Studies in this field have stressed out the importance of action in the creation of thematic relations, as interaction fundamentally shapes how we perceive objects' affordances. Accordingly, thematic relations can be formed between entities which involve action, such as the hammer and the nail, and it has been shown that these are affected by the degradation of the sensorimotor capabilities. Another function which impacts the formation of cognitive relations is inhibition, as poor inhibition typically yields to a preference of thematic relations. However, to our knowledge there have not been any study further investigating the role of inhibition in the detection of thematic relations involving action, which was the main objective of the current master's dissertation. In particular, it was hypothesized that the participants with less inhibitory control will be less effective in the task considering the recognition of thematic relations involving action. This is because they will have difficulty in inhibiting the interference of the distractor object, whereas the opposite would be true for participants with good inhibition. Inhibition was tested using Go/noGo, Navon and Stroop tasks, which are highly popular tasks for such purpose. Moreover, the participants' performance in recognizing thematic relations involving action was assessed using a novel task named DoTIBO. The inquiry was conducted online by using Psychopy, mainly due to COVID-19 restrictions, and it was available for Greek and English native speakers. In total there were 54 participants coming mainly from several places around Greece. The results between the Go/noGo and the DoTIBO tasks validated that the distractor object of the DoTIBO task is associated with the inhibitory control. While the results between the DoTIBO and the Stroop task did not support the current hypothesis. Navon task had irregular results, and they have not been taken into further consideration.

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Abbreviations

TH	Thematic Relation
TH+A	Thematic Relation with Action
TH-A	Thematic Relation without Action
TAX	Taxonomic Relation
UNR	Unrelated Stimulus
SM	Sensory Memory
STM	Short Term Memory
LTM	Long Term Memory
WM	Working Memory
EF	Executive Functions
CF	Cognitive Functions
MM	Mental Model
EC	Embodied Cognition
ISI	Inter Stimulus Interval
RA	Response Accuracy
RT	Response Time
mRT	mean Response Time
STD	Standard Deviation

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Chapter 1
Introduction

In our everyday life, we interact with the environment in numerous ways, by using our sensorimotor capacities, which are vital for extracting meaning from the world around us (Anderson, 2003). For instance, an infant will chew and throw objects to learn their properties (Barsalou, 2008) and a child will play with similar and dissimilar objects, compare, and group the akin together to learn arithmetic (Shapiro & Spaulding, 2021). We can take advantage of the aural or the olfactory sensory systems to further understand a stimulus, which has not been fully understood by the visual preceptors – e.g., soy milk vs cow milk – (Wilson, 2002). Further, we utilize these exploratory qualities and apply them in yet unexamined, more complicated situations, by combining alike characteristics detected in previous experiences (Pecher & Zwaan, 2005). Out of this, we create cognitive relations between objects, themes, and situations (Mirman et al., 2017). Cognitive relations can be broadly defined as thematic [TH] or taxonomic [TAX], which have distinct properties (Nguyen & Murphy, 2003). In TAX relations, the objects' physical properties – i.e., colour, material, odour – are what creates the bond, whereas TH relations are created due to a common event/theme – i.e., cow and milk. As we will see, cognitive [CF] and executive [EF] functions, such as inhibition, can regulate the perception of these relations (Nozari, 2019).

There are two areas in cognitive psychology which try to explain observed phenomena with regard to our cognition and the development of thought. The classical mechanistic view conceptualizes the brain as a distinct entity with different processes which receive inputs, analyse them, and produce outputs, analogous to a computer (Huitt, 2003). According to the second view, cognition is embodied/grounded, meaning that thought is created depending on the emotional, social and physical situation individuals are under and their bodily/sensorimotor capabilities (Barsalou, 2010). Thence, cognition is extended beyond the mechanisms of the brain. One of the key aspects embodied cognition [EC] stresses out, is the importance of action and the affordances between objects (Chong & Proctor, 2020). That is, the possibilities we have when interacting with an object or, in a more Deleuzian view, what an object can give out of its existence (Colebrook, 2002). Tsagkaridis et al. (2014, 2015) investigated further how action affects the TH relations we create between objects. It was found that, in general, thematic relations involving action [TH+A] are preferred over thematic relations without action [TH-A]. However, patients with temporo-parietal lesions were less likely to associate objects based on TH+A, which suggests that sensorimotor capabilities affect semantic organization. Undoubtedly, both positions offer many valuable insights, which help to demystify this unique ability to learn, think and reason based on created cognitive relations.

The current master's dissertation, inspired from Tsagkaridis' novel work, aims to understand better how relations between objects are formed, what is the role of action, and which is the influence of inhibition on them. Nonetheless, before diving deeper in this topic, a more detailed analysis of the aforementioned subjects has to be made. Firstly, the different memory stores, the EF, and the mental model [MM] will be presented for appreciating the inner processes which affect our noesis. Then, the EC will be discussed to support the impact our bodily experiences have, and in particular our actions, on the development of thought. Lastly, we will combine all the above and examine the different cognitive relations in detail.

1.1 Literature Review

1.1.1 Classical View of Cognition

There is a chance that the classical orientation of cognition has its origins from Plato's innatistic views of perception (Grönroos, 2001), forward on to the Age of Enlightenment and the rationalistic position of Descartes' body and mind dualism (Pecere, 2020) and further on to contemporary nativists, such as Chomsky and his universal grammar theory (Barman, Binoy, 2012). In these theories, the principal notion is that cognition is separated from the environment. Based on the philosophical or psychological discipline, this distinction can be less or more permissive. Innatists support that everything is already there, in our psyche. Namely, there are fully fledged and developed constructs which guide thinking (Vosniadou & Brewer, 1987). Nativists argue that there are innate concepts, which shape the essence of cognition, but there are pure, basic and generic. More complex and specific concepts are created in later stages, through experience, based on these pure constructs (Vosniadou & Skopeliti, 2014). As an analogy, we could imagine an artificial agent which is pre-coded and acts based on a number of rules, and a machine that has a basis, such as a pre-developed artificial neural network, or a basic set of rules which the agent uses them to find logical patterns. This mechanistic perspective sparked the urge for investigating the individual parts which form the foundation of cognition.

1.1.1.1 Memory Stores

Back in the 1890s, William James was the first to conceive that memory lies in different stores. In his work, he made the distinction between primary memory, a temporarily conscious storage of current events, and secondary memory, an unconscious unlimited pool of information (James et al., 1890). Atkinson and Shiffrin, inspired from this idea and the emerging field of computer science, gestated three different memory stores (Malmberg et al., 2019).

Sensory Memory: The first one, sensory memory [SM], is dedicated to parsing all incoming information from external stimuli. It is transient, with variable but very short duration between senses, without retention limitations, and automatic –i.e., incapable of voluntary control. SM is typically evaluated with priming tasks, like a set of images presented for less than 50ms. In such tasks, participants can successfully recall more than half of them. Similar arguments supporting SM have been found for all senses (Köster & Mojet, 2017). It is vital to note that sensory memory is not the same as the after-image, which is the continuation of the chemical activity in our receptors after extended exposure to a stimulus (Luck & Hollingworth, 2008).

Short Term Memory: The attended information from the SM passes to the short-term memory [STM], which is analogous to primary memory. Unattended information is getting lost. STM can hold information for a longer period, but it is limited both in terms of storage and duration, as it can store approximately 7$\pm$2 items, for the maximum time of approximately 30 second (Plancher & Barrouillet, 2020). However, information in STM can be prolonged and expanded by actively rehearsing it and/or chunking it together, respectively (Thalmann et al., 2019).

Long Term Memory: Eventually, conscious or unconscious information maintained in STM can be encoded and passed on to long-term memory [LTM], a store similar to secondary memory, which is considered unlimited both in terms of duration and retention. Atkinson and Shiffrin supported that knowledge is getting transferred from STM to LTM with repetition, and that information stored in LTM can be retrieved at command back to STM for further utilization.

The Atkinson-Shiffrin model has many limitations and has been criticized extensively throughout the years. Nevertheless, it has set the frame in which most cognitive scientists have based on and expanded their ideas (Malmberg et al., 2019). One of the weakest parts is its simplicity. In particular, this model does not provide any suggestion on the way information is manipulated on STM, how thought emerges, and the different mechanisms involved in these processes (Plancher & Barrouillet, 2020). Furthermore, the LTM excludes specificity regarding the nature of the encoded content. Learning through repetition is another issue which has not been supported by the scientific community (Craik & Watkins, 2016), as it has been found that deep comprehension is a better predictor for knowledge acquisition (Plancher & Barrouillet, 2020). The development of more precise tools for examining cognitive processes led to more detailed models, which have increased our understanding. However, the presentation of more complex models is out of the scope of this master's dissertation.

LTM Subcategories: According to Atkinson and Shiffrin, LTM is a general pool of attained knowledge. However, studies with amnesic patients and neuroimaging tools demonstrate a distinction between different types of knowledge founded in LTM. Specifically, findings indicate two main stores, the declarative/explicit memory and the procedural/implicit memory. Explicit memory is subcategorized further to the episodic memory, which holds autobiographic, self-experienced memories (Rovee-Collier et al., 2001), and the semantic memory, in which all general knowledge, concepts of the world and language exist (Binder & Desai, 2011). Implicit memory stores automatic responses, either from emotionally conditioned experiences or through proceduralization (Rovee-Collier et al., 2001).

Semantic Memory: In the classical view of cognition, semantic memory is considered a store of abstract, amodal and timeless representations of the disparate entities found externally (Gainotti, 2011). Compared with episodic memory, in which memories are bound to time, information in semantic memory is not based on particular events –e.g., we do not know when the concept of the world being spherical was created– (Gage & Baars, 2018c), nor contains any modalities – i.e., emotional, or sensational information

– (Gainotti, 2011). For this reason, semantic memory is most frequently illustrated as a graph, with the nodes being entities connected with other nodes via weighted edges (Rogers & Mcclelland, 2004). For instance, the entity *moon* can be connected with other entities, such as *satellite*, *night* or *love*. Through this graph, TH or TAX relations can be extracted. In such representations, TH or TAX relations can be a decisive factor of concepts association.

Working Memory: Baddeley and Hitch proposed the working memory [WM] model as an addition to Atkinson and Shiffrin's STM (Baddeley, 2012). WM can be conceived as a working bench which actively manipulates information retained in STM. WM consists of four components. The *phonological loop* is in charge of the aural stimuli, but also language – spoken or written – and articulation. The *visuospatial sketchpad* manipulates everything related with vision and direction. These two components are capable of working in parallel without any interaction. The *episodic buffer* is a bridge between acquired knowledge found in LTM and STM. Thus, the *episodic buffer* shapes current events with previous knowledge. The *central executive* is the place where the coordination of the previous three components is done and includes executive functions [EF], like inhibition, updating, decision-making, shifting, and selective attention.

Neuroanatomically, it has been found that WM's major activity is located in the pre-frontal cortex, though not all of its processes take place solely in this area. More specifically, tasks involving the *phonological loop* reveal high activation in the left pre-frontal cortex – Broca's area – and the temporal lobe. The *visuospatial sketchpad* activates different regions depending on the task. In simple tasks, the occipital lobe is active, while more complex tasks activate the parietal lobe. The *episodic buffer* activates both hemispheres and parts of the hippocampus. (D'Esposito & Postle, 2015)

Inhibition in the Classical View of Cognition: Inhibition is defined as the ability to suppress automatic responses for the preference of more suitable ones, based on the given situation (Gage & Baars, 2018d). This control can be valuable, as it is critical in planning ahead or making strategic decisions. However, inhibition does not act solely on social/behavioural or emotional/interpersonal responses, but also on intellectual – i.e., suppressing irrelevant from relevant acquired knowledge. For example, Nozari (2019) examined aphasic patients with damaged inhibitory control and found that they had difficulty in retaining unrelated activated semantic knowledge. Inhibition has three functions: *access*, *deletion* and *restrain* (Yin & Peng, 2016). Inhibition acts as a gateway to WM and gives *access* solely to goal-relevant information. *deleting* is the ability to suppress information which becomes irrelevant, but has been previously activated and accessed WM due to their relativity. *Restraining* is the suppression of an automatic dominant response to another less probable.

In addition, it has been found that inhibition depends on age, in which children and elderly people exhibit less inhibitory control than middle-aged and adolescents (Hasher et al., 1991). It should be noted that inhibition is not the same as selective attention and distraction, despite the fact that it is closely related to them, as poor inhibitory control can render similar effects. Selective attention has a bottom-up processing, as it blocks external information from our senses, either because excitation of our sensory organs does not exceed a given threshold or because WM is highly loaded with other tasks, and it cannot process more information (Gage & Baars, 2018b). Inhibition on the other hand relies on prior knowledge and blocks automatic/impulsive responses (Moorselaar & Slagter, 2020).

1.1.1.2 Mental Model and Learning

There are opposing views on how thought emerges out of the above-mentioned processes. One of them is that cognition is rule-based, according to which inferences are drawn from logical formal rules – i.e., if A and B then C – (Gage & Baars, 2018a). The Mental Model [MM], in contrast, is a representation fabricated mentally in a given situation, which requires all aforesaid processes to be combined (Richardson et al., 1994). Hence, WM manipulates perceived information stored in STM with the activated parts of LTM, while inhibition prohibits the interference of irrelevant information. This is an intentionally simplified picture of the MM, including the parts mostly related to this master's dissertation, and by no means does it describe a complete picture of the MM. There can be competing MMs at times, but only the successful ones are kept while the rest are discarded. Successful MMs are not objectively true, but individualized based on previous experience (Richardson et al., 1994).

The MM is not passive, as it can actively *assert*, *tune* or *restructure* the current schemata found in LTM. As already noted, in the nativistic view, a child is born with innate concepts essential for learning. Such concepts may involve the recognition of where objects start and end (Chi & Ceci, 1987), or fundamental grammatical understanding which make the child capable of learning language (Barman, Binoy, 2012). Based on this view, the knowledge graph is developed and enhanced on top of these concepts. Assertion adds new features to an already established concept – i.e., a child could play with a ball by rolling it, and suddenly realize that this ball can also bounce if thrown away. Tuning adjusts parts of a concept which are not valid – i.e., tomato could be connected with other vegetables due to their TH relations, but tuned to fruit due to TAX relations. Finally, restructuring is when current concepts are invalid altogether and new ones replace them – i.e., earth-centric versus a heliocentric perspective. Old concepts are not deleted, but inhibited due to their invalidity (Boshuizen et al., 2020).

1.1.2 Embodied Cognition

Embodied cognition rejects the mind-body separation, in which the brain is the computational unit – the source of cognition, while the body is the object guided from the subject (Shapiro, 2019). In contrast, it suggests that cognition extends to the body, beyond the brain, and it cannot exist isolated from the environment. Thus, according to EC, we are not born as thinking things but as acting entities. Children have drives to move and interact to learn their bodies and the world. The blockage of these actuations fundamentally shapes their reality and thought (Barsalou, 2008; Ionescu & Vasc, 2014). Something especially interesting regarding this topic is how the embodiment of gender roles shapes perception and cognition, see Mason (2018). Heidegger famously established the term "Dasein", which is translated as "being there", "exist in the world" (Anderson, 2003). According to him and other phenomenologists, like Husserl, who opposed to Descartes' ontological positions, existence precedes cognition (Shapiro & Spaulding, 2021). Hence, our bodily experiences and interactions with the world are what establish cognition, or, as Heidegger sees it, knowledge and thought is flourished by revealing the properties of the environment through exploration (Blitz, 2014). EC is a multidisciplinary field, which unites phenomenological, neurological, psychological, anthropological and biological concepts (Shapiro & Spaulding, 2021). Below are the cardinal notions of EC, which will be further elaborated:

1. Cognition is made from multimodal and not from abstract symbolic concepts (Barsalou, 2010).

2. Abstract and imaginative concepts are still body based (Pecher & Zwaan, 2005).

3. Action is key to cognition (Wilson, 2002).

4. Cognition is not bound to thought in terms of linguistic expressions; rather, it can be in a form of non-rhetorical actions (Núñez, 2006).

5. Cognition is constrained to the individuals' physical characteristics and to the given socio-environmental liberties – conceptualization (Shapiro & Spaulding, 2021).

6. Cognition is situational and time dependent (Wilson, 2002).

7. Cognition is extended to the environment – cognitive off-loading (Wilson, 2002).

1.1.2.1 Cardinal Principles of Embodied Cognition

Cognition is Multimodal: Plentiful studies show that the mere imagining of acting upon an object stimulates the motor cortex of the brain (Anderson, 2003; Barsalou, 2008; Shapiro, 2019). Similarly, parts of the brain connected with the other sensorimotor systems are getting activated just by thinking, like in the case that the thought of an object stimulates the visual regions of the brain (Pecher & Zwaan, 2005). The opposite is also true. As already mentioned, Tsagkaridis et al. (2014), stressed out the positive correlation between the usual function of brain areas connected with movement and the recognition of object relations which include action. This suggests that information is not amodal and abstract, but constructed based on the sensorimotor involvement. The brain actively reconstructs, or re-experiences, previous comparable circumstances to current situations, in what is known as perceptual symbols or embodied concepts (Shapiro, 2019) and the degradation of either the senses, or the brain, would determine the kind of these concepts.

Embodied Cognition in Abstract Concepts: Cognition can be considered as online or offline (Wilson, 2002). Online cognition refers to the greatest part of our reality, as it has to do with everything related with current events, and it falls vastly to procedural/automatic actions (Koziol et al., 2012). Offline cognition relates to abstract concepts – i.e., freedom, democracy –, daydreaming and introspection, mathematics, imagination, and others (Pecher & Zwaan, 2005). EC is not limited to online thinking, rather, there is support that offline cognition uses the current bodily state of affairs too (Wilson, 2002). This can be easily observed in the learning of abstract concepts, and mathematics, as learning is more effective by relating this information with objects or concrete concepts found in our surroundings (Barsalou, 2008; Núñez, 2006). Additionally, there is an intriguing work carried out by Núñez (2006), which attempts to explain the embodied nature of mathematics. Other studies have found that the motor cortex is activated in the perception of abstract content, suggesting an embodied correlation (Shapiro, 2019).

Action: There seems to be a strong relation between cognition and movement. This is prominent in other animals, especially mammals, which play and move their bodies to learn essential survival skills such as hunting, gathering resources and reproducing (Gray, 2019). In consonance with Koziol et al. (2012), humans have not evolved driven by passive thinking but by surviving on the environment through active exploration, which requires movement. A striking finding supporting this notion is the hand gestures in language production, which facilitate perception, comprehension, and the organization of thought; while more fascinating is the observation that languages tend to enforce their unique gestures (Hubbard et al., 2009; Spivey et al., 2009). Similarly, a negative correlation has been found between locomotor skills and learning disabilities (Koziol et al., 2012).

Affordances: Gibson (1977) was the first to set the frame of affordances in cognitive psychology, which is similar to the Deleuzian and Heideggerian views, mentioned above, regarding knowledge extraction. Conforming to this, objects acquire their meaning from the applications they can offer. For instance, a hammer obtains its identity when it is used for something purposeful for the user. This implies that the meaning lies in the relation, which is arbitrarily created based on the environment, but also on the abilities and needs of the perceiving person. A hammer is most often used for nailing items to walls, still children would be less likely to extract this affordance. For them, it might be too heavy to hold, shaping it useless. Thence, affordances are not pre-destined but created or further developed or restructured over the course of continual interaction. Undoubtedly, there are sociopolitical conventions which guide our actions and perception and make some affordances more probable than others (de Carvalho, 2020). Nonetheless, as we can observe, humans are able to drastically manipulate the environment with the desire to extract new affordances.

Cognition is Time Dependent: A common objection against the classical view of cognition is that it is computationally inefficient (Wilson, 2002). In particular, robots inspired from the classical view of semantic memory are too slow to adequately find or construct the correct inferences for a given situation, which leads to delayed responses (Anderson, 2003). This is also prominent in controlled environments without unexpected stimuli (Wilson, 2002). The environment is continuously changing, and it is filled with unpredicted circumstances. For this reason, it would be impossible to successfully interact with it by constructing representations before acting. On the contrary, robots aspired from EC yield better results in the interaction with the environment.

Cognition is Situational: Cognition is not affected only by time, but from the current physical and emotional situation an individual is under (Lakoff, 2012). Williams and Bargh (2008) showed that interpersonal warmth is affected from environmental factors such as a warm cup of coffee. In a similar study, participants were asked to remember experiences where they felt socially accepted or the opposite. It was found out that the group with pleasant memories felt the surrounding temperature 5 degrees higher on average compared to those with unpleasing ones (Zhong & Leonardelli, 2008).

Cognitive Off-loading: There are some EC views which suggest that cognition extends beyond our bodies (Wilson, 2002). These perspectives become even more relevant in today's world of information, in which information is so massive that it is impossible to be retained into one's mind. Writing was a major breakthrough in human evolution, as it enabled humans to off-load their 'workload' onto their environment. In our current society, we off-load our knowledge with numerous storage methods, such as notepads, electronic devices and other. For example, we do not explicitly know each number in our contact list, but we know where and how to find them. Hence, we cannot say that cognition ends where our body ends.

1.1.2.2 Inhibition in Embodied Cognition

Based on the embodied view of cognition, inhibition plays an additional role in cognitive relations. While in the classical view of cognition inhibition acts as a blocking mechanism for all created schemata, in EC it also blocks possible modalities, which would subsequently influence all candidate inferences. For this reason, the embodiment of a more restrained way of living – the restriction of action, vision or other modalities – will shape cognition and the formation of relations between entities.

1.1.3 Cognitive Relations

Saussure showed in his semiotics theory that the meaning of a symbol is nothing but the relation and more specifically its difference against other symbols (Chandler, 1994). This is in tandem with the classical cognition view, which describes the MM and the knowledge graph located in the semantic memory. This is a highly convenient and useful analogy for understanding how inferences are created. Still, the MM cannot be considered as a full-fledged concept. EC stresses out that inferences are not amodal representations, which are *asserted*, *tuned* or *restructured* from experience and at the right moment are activated, while inhibition blocks all unrelated activations. On the contrary, there are modalities within them (Haimovici, 2018). This implies that based on the given moment, the environmental situation – actions and interactions – will fundamentally influence the created relations. Thus, they are not static but always changing dynamic entities.

1.1.3.1 Taxonomic Relations

TAX relations are those that occur between signs with similar characteristics. For example, all different kinds of birds fall into the same TAX category as they have a number of similarities such as wings, feathers, lay eggs etc. TAX relations are hierarchically formed, and their rank is bound to their taxonomic similarities (Nguyen & Murphy, 2003). For instance, a *parrot* with an *eagle* and a *penguin* share many attributes, so they have a high rank. However, the *penguin* will be placed a bit lower because it cannot fly compared with the other two.

1.1.3.2 Thematic Relations

In contrast with TAX relations, the concepts in TH relations can have dissimilar characteristics. This is because their relations are created based on mutual temporal or spatial events – e.g., cereals and milk. It is worth noting that most of these concepts are formed from experience and are restrained to the cultural and social norms of the environment (Betz & Coley, 2020).

Borghi and Caramelli (2003) further elaborated, the TH relations in five subcategories. The spatial TH relations – e.g., sound engineer - recording studio –, the temporal TH relations – e.g., beach - summer –, the interrogative TH relations – e.g., bird - fly –, the TH relations regarding operation – e.g., kitchen table - eat –, and the TH relations regarding more complex multidimensional situations – e.g., sofa in psychotherapy - divan.

Lastly, as already mentioned, Tsagkaridis et al. (2014) showed TH relations can be further categorized based on the interaction they have with each other. Hence, TH relations can additionally involve action – screw - screwdriver.

1.1.3.3 Properties Between Taxonomic and Thematic Relations

Many studies have shown that the preference of TAX or TH relations is correlated with age (Belacchi & Artuso, 2018). In particular, children till the age of 5 have either a strong preference on TH relations or no preference. Similarly, elderly people seem to prefer TH relations, whereas in in-between ages there is a preference for TAX relations (Mirman et al., 2017). A possible explanation of this is that children develop the required cognitive capabilities for recognizing TAX relations in a later state, after 5 years old (Blaye & Bonthoux, 2001) and lack previous knowledge, which is vital for understanding TAX relations. Children seem to learn through exploration at that age, which promotes the creation of TH relations. This pattern is similar with the pattern observed with inhibition and age. Thus, inhibition could be the reason elders show a preference for TH relations, while youths are attracted to TAX relations. More specifically, TAX relations seem to need more inhibitory control than TH relations, which appear to be more automatic (Mirman et al., 2017). This could be due to the way we learn these relations, as TAX relations require more cognitive effort to be learnt.

Another interesting study supported that participants from rural areas are more likely to prefer TH relations than those who grew up in urban environments (Betz & Coley, 2020). Likewise, typical education yields a preference on TAX relations whereas TH relations are usually preferred by children whose education derives mostly from environmental exploration and in general enforced action and interaction (Mirman et al., 2017). These results can strengthen the EC views and support the importance of action in learning and how this can shape cognition.

1.2 Current master's dissertation

The aim of the current master's dissertation is to explore the role of inhibition in relations between objects involving action. For this, four tasks will be used: The first – DoTIBO task – is a novel test developed by Tsagkaridis et al. (2014), which evaluates the participants' cognition on thematic relations involving action [TH+A]. The second and the third are typical tasks used in cognitive psychology, which assess inhibition, namely the Stroop and the Go/noGo task. The last one is the Navon task, which measures the preference of the participant on *Global* or *Local* stimuli. All tasks are described in detail in chapter 2.

Our main hypothesis is that there is a positive correlation between the performance and the response time in Stroop and Go/noGo tasks and the performance of DoTIBO task. It was already mentioned that the preference of TH relations is more automatic than TAX relations, as TAX relations need higher inhibitory control. For this reason, it is logical to assume that higher inhibition will aid in suppressing the interference of the distractor object in the DoTIBO task, which will have a positive effect in the test's overall performance. The second hypothesis is that those participants who prefer *Global* stimuli in the Navon task will perform better in recognizing TH+A relations. On the contrary, accuracy in recognizing TH+A relations will decrease in those who prefer *Local* stimuli. The same pattern was shown in TH and TAX relations in Guest et al. (2016), nevertheless it has not been examined before on TH+A relations. Attending the *Local* stimuli in the Navon task requires a higher activation of the inhibitory function than *Global* stimuli, which suggests that *Local* vs *Global* stimuli preference is associated with this EF (Hine & Itoh, 2018).

Chapter 2
Methods

2.1 Materials and Design

The experiment was built using the Psychopy toolkit, a program specifically designed for psychological experiments developed in Python programming language (Peirce et al., 2019). We decided beforehand to run the experiment online, mainly due to the coronavirus pandemic restrictions, but also for the pursuing of a more diverse group of people. Psychopy allows running experiments online using their web interface Pavlovia, which according to a recent study, it was found to be the most robust online experimentation tool with maximum latency of 3ms Bridges et al. (2020). These results promote a smooth interaction for the participants, providing valid and concrete results.

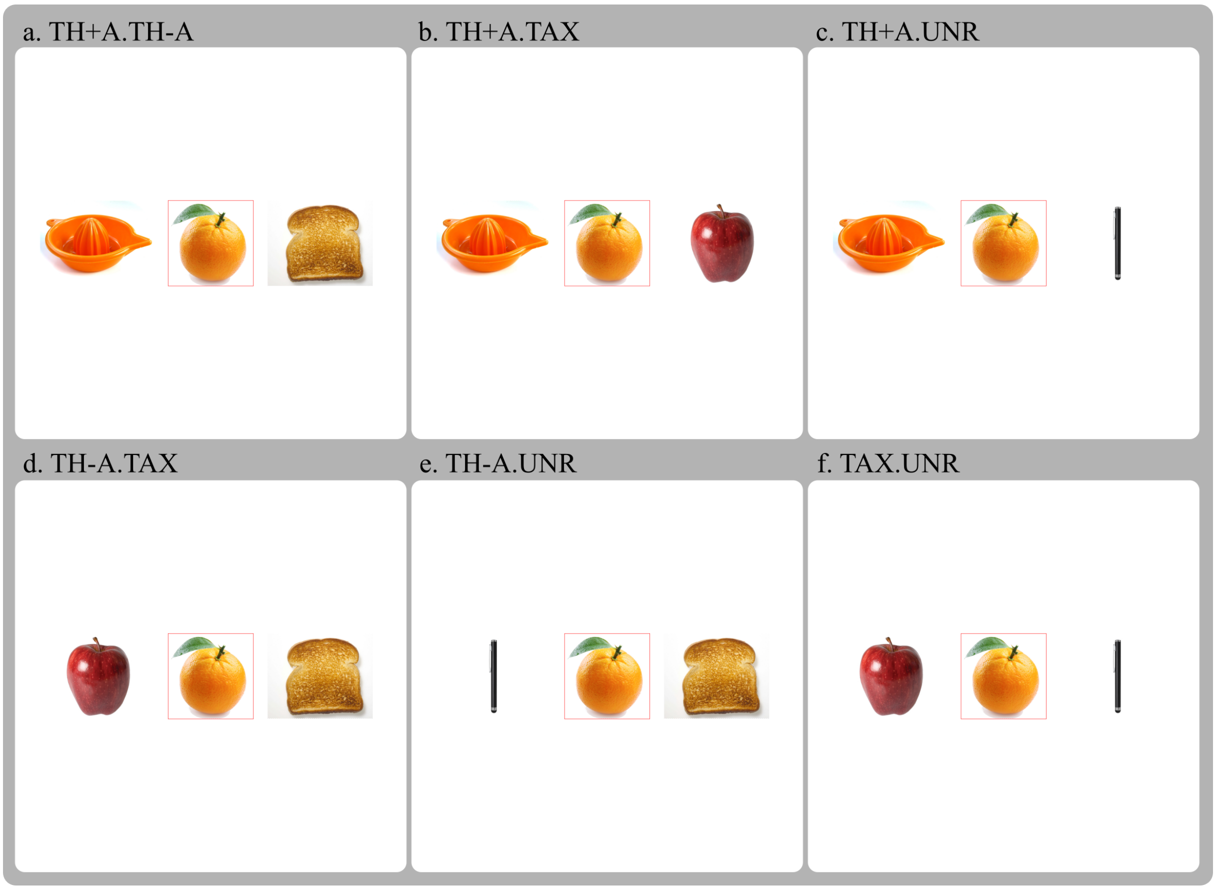
The experiment was available in two languages – English and Greek – and it consisted of four tasks, which were presented in a random order. Each task had its own training phase, the data of which were not taken into consideration in the analysis. The dimensions of the stimuli mention below were demonically adjusted based on the dimensions of the screen – i.e., 6% means that the stimuli filled 6% of the screen in both axes.

2.1.1 Detection of Typical Interaction Between Objects Task [DoTIBO]

The most common way of evaluating the cognitive relations between objects, such as their TH and TAX relations, is with matching-to-sample tasks (Estes et al., 2011). In these tasks, the participants are called to choose which of the provided objects suits best for a corresponding target. The objects can be of any nature – pictorial, textural – and each target-object relation can be TH, TAX, or it can have no relation [UNR] with the target.

Tsagkaridis et al. (2014) developed DoTIBO, a novel task that follows the same logic as the common matching-to-sample tasks, with the introduction of an extra variable of action/interaction between the objects. Thus, it further investigates the role of TH+A and TH-A. DoTIBO consists of a target object-image in the centre of the screen hinted with a red stroke and next to it, left and right in the same height, there are two object-images without any stroke. The background of the task and the images is white, effectively blending the individual images together in a triad. The images are in RGB colour. There are six possible triad combinations: *TH+A.TH-A*, *TH+A.TAX*, *TH+A.UNR*, *TH-A.TAX*, *TH-A.UNR*, *TAX.UNR*. Figure 1 shows an illustration of all possible target-object combinations.

Figure 1: Conditions of the DoTIBO task. The orange has a TH+A with the orange juicier, a TH-A with the bread, a TAX with the apple, and it is completely unrelated with the tablet pen.



In the current task, there were 37 trials for each triad combination, making a total of 222 trials. For minimizing bias, another block of 222 trials was presented, in which the objects of each triad swapped positions – i.e., the right object moved to the left position and vice versa. Hence, the total number of trials of the task were 444. Except for these trials, 12 sample trials were presented in the beginning of the task for familiarization. The presentation of the blocks and their trials were random. Before each trial, a fixation cross, 3% wide, was shown in the centre of the screen indefinitely, till *SPACE* key was pressed. When the *SPACE* key was pressed, a triad was shown for the maximum time of

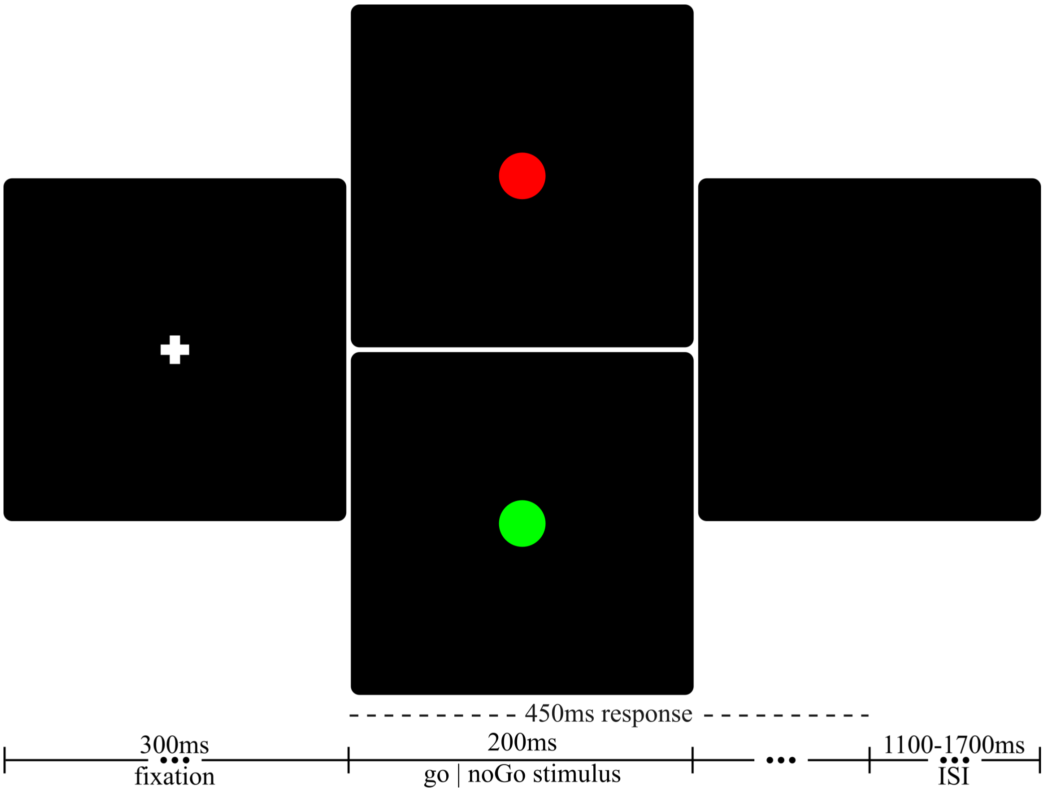
2 seconds. At that time, the participant had to make a choice. If the time was exhausted or a choice was made, the trial terminated and went back to the fixation point, starting a new trial. The dimensions of each picture were 3%. The participants were explicitly asked to find the TH+A target-object relation. If such a relation occurred between the left object and the target, then the *LEFT* key should be pressed. Likewise, the *RIGHT* key should be pressed if there was a TH+A relation between the right object and the target. Lastly, if there was no TH+A relation between the object and the target, then the *UP* key should be pressed. By the termination of each trial, the response time [RT], the answer – *LEFT*, *UP*, *RIGHT*, *NONE* – and its correctness were recorded.

2.1.2 Go/noGo Task

Go/noGo tasks are well known when it comes to the examination of inhibition (Guo et al., 2018). Although there are some reviews which contradict this statement, like Criaud and Boulinguez (2013) who recently suggested that Go/noGo tasks do not examine inhibition per se, but the engagement of working memory or high attentional processes. Nonetheless, there are many studies which demonstrate that in overall, Go/noGo have high validity and reliability in measuring inhibitory control. The goal of this task is to respond to the *Go* stimulus and suppress any response to the *noGo* stimulus. The stimuli can be of any nature – aural, pictorial, textual – or a multimodal combination of them (Kirchner & Colonius, 2005). For example, the *Go* stimulus can be the letter *S* or a picture of a *dog* and the *noGo* the letter *O* or a *"beep"* sound. Typically, the *Go* stimuli are more frequent compared to the *noGo* in a ratio of 7:3, 8:2 or likewise. Additionally, other studies implement an extra layer with a third infrequent *Go* stimulus for added complexity and difficulty (Hirose et al., 2012).

The present master's dissertation incorporated a classic paradigm of a *GREEN* and *RED* dot as a Go/noGo stimuli, with a 7:3 ratio. Each trial started with a fixation cross, coloured white, in the centre of the screen with size 4%, which was shown for 300ms. Afterwards, the stimulus with size 6% appeared for 200ms, likewise in the centre of the screen. The response could be made from the moment the stimulus appeared up until 450ms later by pressing the *SPACE* key. After the response, an inter-stimulus interval [ISI] was activated for a randomly assigned duration between 1100ms and 1700ms. The background of every screen was black. In total, there were 120 trials divided in two blocks, with a random order of presentation. Therefore, half of the trials had the *GREEN* colour as the *Go* stimulus and the *RED* colour as a *noGo* stimulus, while the other half had the opposite. Additionally, 20 trials were presented in the beginning of the task for training. See Figure 2 for a detailed illustration regarding the sequence of this task. Similar with the DoTIBO, the RT, the response – *SPACE*, *NONE* – and its correctness were saved for each trial.

Figure 2: Illustration of the Go/noGo task sequence.



2.1.3 Navon Task

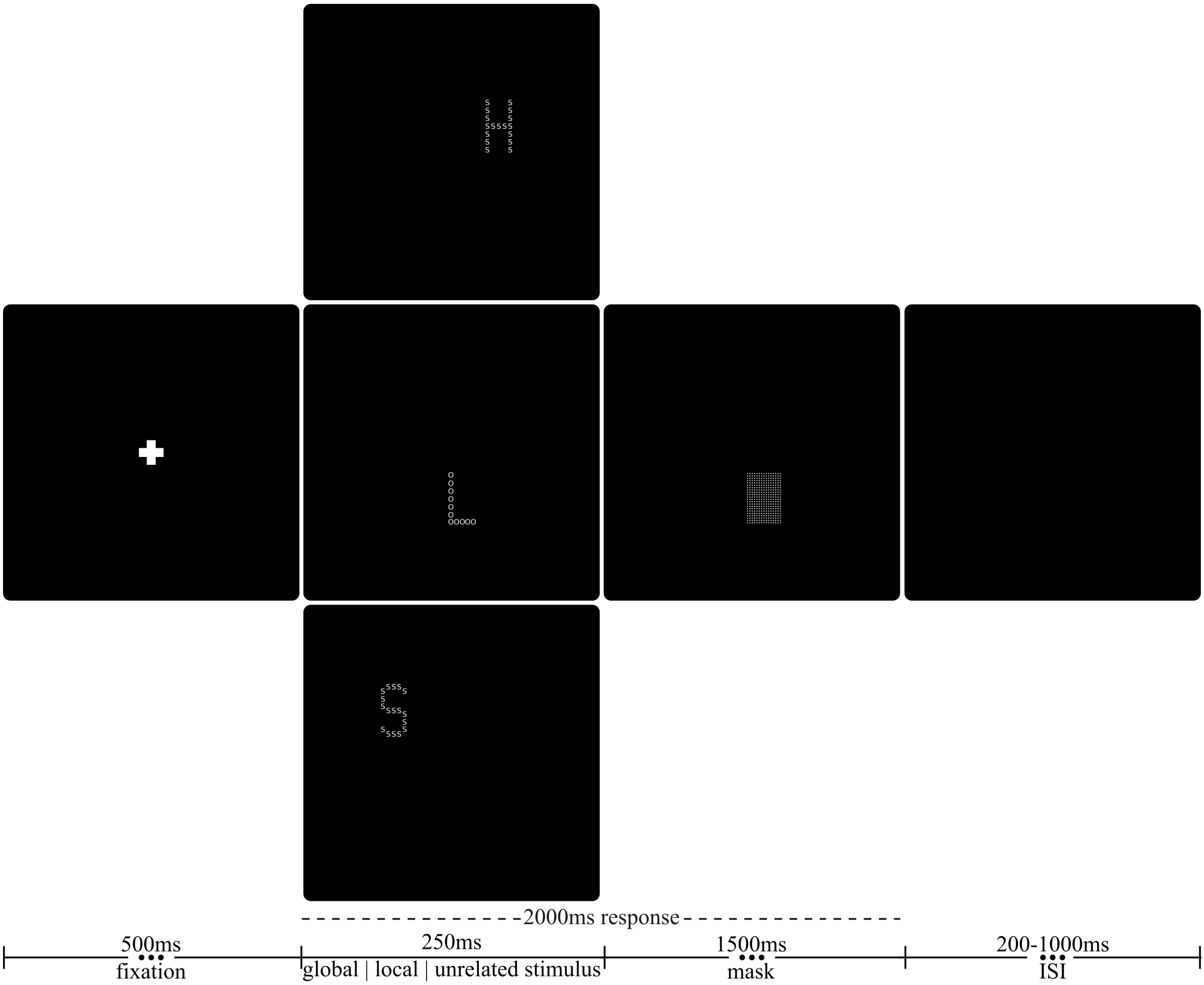
David Navon first introduced his experiment back in 1977 in his paper *"Forest before trees"* (Navon, 1977). His aim was to find out whether individuals are inclined to attend the *Global* features of a stimulus – *"forest"* – or the *Local* – *"trees"*. The results suggested that people are more prone to the *Global* perspective of a stimulus. His test included some compound letters constructed from other smaller letters. For example, a letter *H* made out from small *x* –denoted as *Hx*. The participants had to respond if the stimulus had an *H* or an *S*, first on a *Global* and then on a *Local* level. Moreover, in order to avoid the participants' predictive behaviours to produce biased results by knowing where to look to find the answer, Navon randomized the presented location of the stimuli. Although this task shows a preference towards the *Global* attention, it should be noted that there are concerns regarding its application to the broader and richer natural world, as this task is carried out in a simplified environment (Gerlach & Poirel, 2018).

In the current master's dissertation, the concern was mostly on the individuals' difference between the *Global* and *Local* stimuli. For this reason, Stoet's (2021) implementation of the Navon task seemed the most appropriate. The participants had to respond if the stimuli included the letters *H* or *O*, either on a *Global* or on a *Local* level. In particular, the participants should press the *LEFT* key if there was an *H* or an *O* either in the *Global* or *Local* level and the *RIGHT* key otherwise. There were four *Global* stimuli, four *Local* stimuli and eight *Unrelated* which acted as control. The complete list of stimuli (see Table 1a) was randomly presented 5 times, leading to 80 trials in total. In the beginning, there was a training period of 16 trials. Each trial started with a white cross, with size 3%, which behaved as a fixation point. It was shown in the centre of the screen and lasted for 500ms. The stimuli appeared after the fixation for 500ms, and it was masked for another 1500ms. Both stimulus and mask were white and had size 3%. In each trial, they appeared in a random place of the screen, but not too far away from the centre. The task had a black background covering the whole screen. The participants could respond from the moment of the appearance of the stimuli till the end-time of the mask, else it automatically ended the trial. Any response immediately terminated the trial and started an ISI for a random period of 200ms to 1000ms. The task saved the RT, the response – *LEFT*, *RIGHT*, *NONE* – and its correctness for each trial.

2.1.4 Stroop Task

Stroop task, named after John Ridley Stroop, is one of the best known tasks in cognitive psychology. It is more than a half century old, with well established reliability and validity in measuring inhibition. The original task consisted of coloured words. The participant had to tell the colour of the stimulus and not the written word. The task consisted of *Congruent* trials, in which the colour and the word had the same value – e.g., word *BLUE* in *BLUE* colour – and *Incongruent* trials in which the colour and the word were dissimilar – e.g., word *BLUE* in *RED* colour –, with the word being a colour (Stroop, 1935) Throughout the years, numerous variations have been implemented by using other visual or aural stimuli (Fernandes, 2018), biased weighted conditions towards *Congruent* or *Incongruent* stimuli (Braver et al., 2021) and/or with inclusion of *Control* stimuli, which can be unrelated words or a sequence of same letters – e.g., *HOUSE*, *DOG*, *XXXXXX* – (Henik & Salo, 2004).

Figure 3: Illustration of the Navon task sequence.



The current master's dissertation followed Martina's 2019 experimental design, which implements a version based on the original one, with the addition of a list of *Control* stimuli. More specifically, the overall task is balanced across all conditions with eight trials of *Congruent* stimuli, eight trials of *Incongruent* stimuli and eight trials of *XXXXXX Control* stimuli. Only four colours have been used, namely: *RED*, *BLUE*, *GREEN*, and *YELLOW*. Table 1b summarizes all the conditions used. The participants were instructed to press the *Z* key if the colour was *RED*, the *X* if the colour was *BLUE*, the *N* key if the colour was *GREEN* and the *M* key if the colour was *YELLOW*. The 24 trials were randomly screened 5 times, adding up to the total of 120 trials. There were 48 training trials for familiarization. The background of the task was black. Every trial started with a white fixation cross, in the centre of the screen, for 1000ms, with size 3%. Thereafter, the stimulus was presented, in the centre, with size 4%, for 1500ms during which a response should be made. By the completion of this time or with the participants' response, a fixed ISI of 1000ms started before the initialization of the next trial. Similarly, with the other tasks, the RT, the response – *Z*, *X*, *N*, *M*, *NONE* – and its correctness were saved for each trial.

Table 1: Conditions of Navon (a) and Stroop (b) tasks.

Global	Local	Unrelated	
Hs	Lo	Ll	Ts
Ht	Sh	Lu	Tt
Ol	Th	Ss	Ul
Ou	Uo	St	Uu

(a)

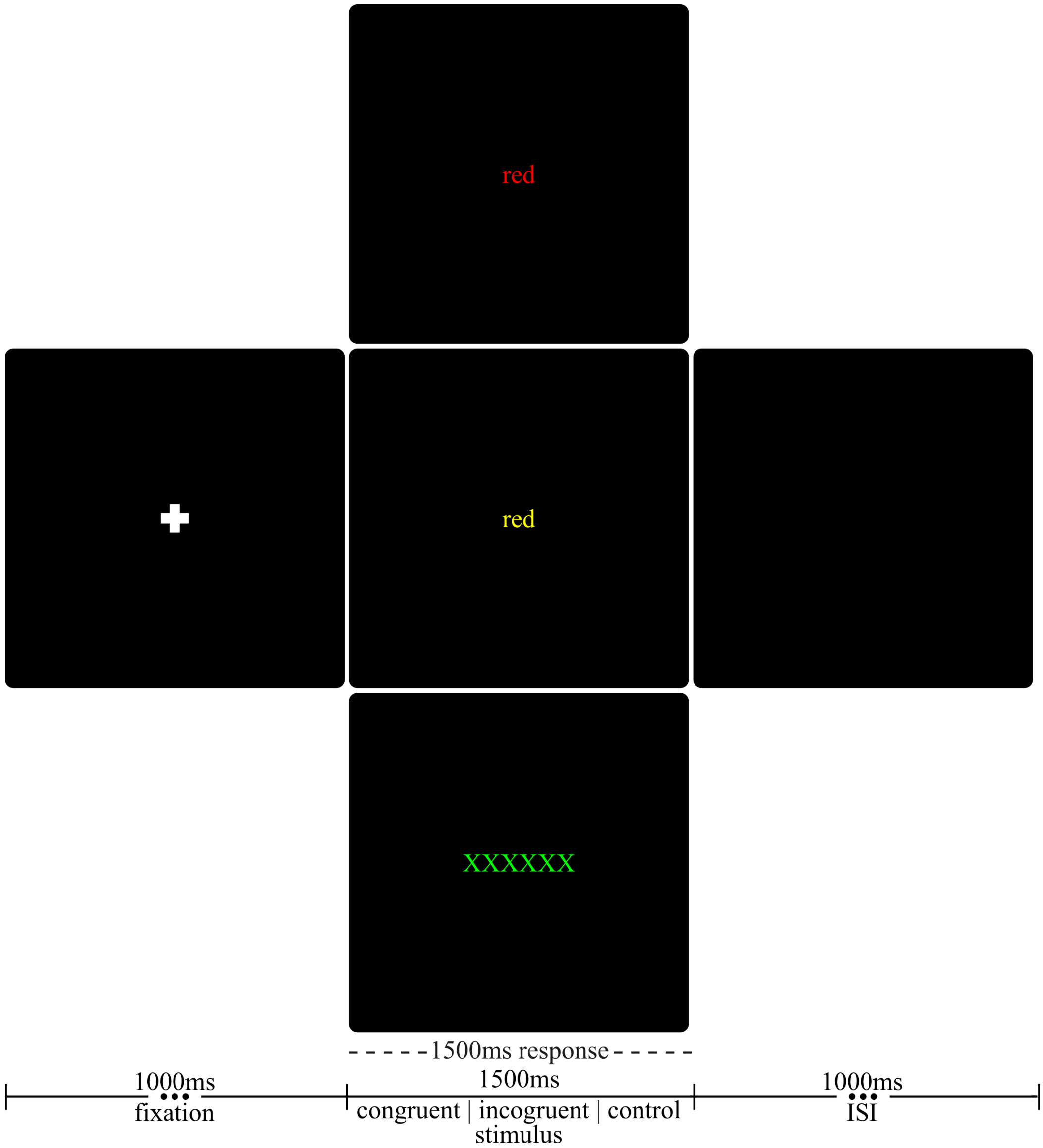
Congruent	Incongruent		Control
RED	RED	RED	XXXXXX
GREEN	GREEN	GREEN	XXXXXX
BLUE	BLUE	BLUE	XXXXXX
YELLOW	YELLOW	YELLOW	XXXXXX

(b)

2.2 Procedure

The participants were gathered from various sources including online groups, close friends and relatives, friends of friends and people studying in the same university. The ones interested in participating in this master's dissertation were contacted privately to arrange the time and day in which they could carry out the experiment. It was instructed to do the experiment when they had some extra time and were able to be in a quiet room without external interferences, but also at a time when they felt energized. At the day of the appointment, a link of the online experiment was sent to them. The experiment started by asking some essential demographics, presenting the main idea of this master's dissertation and how the experiment is going to be held. They had to press the key *ENTER* to proceed to the following pages. In the last page of the introductory information, there was the written consent in which they agreed if they wanted to continue further. Subsequently, the tasks proceeded one by one in random order, first in the training and then in the testing phase. Before the initialization of each task, there were instructions explaining how the task works and what the participant should do. Moreover, the instructions were prompted again before the beginning of the testing phase as a reminder. There were no dedicated breaks in between each task, however it was recommended to take extra time on the instructions page of each task in case they felt tired. By the completion of each task, a statement was shown signalling its ending. The data were saved

Figure 4: Illustration of the Stroop task sequence.



in Pavlovia's server and could be downloaded upon demand.

2.3 Participants

In total, 54 people voluntarily participated in the experiment of the current master's dissertation. Out of them, 42 were females, with their mean age being 37.7 – SD: 14.4 –, and 10 males with a mean age of 36.7 – SD: 7.689. Concerning their educational status, 2 of them have completed junior high-school, 7 of them were high-school graduates, 24 of them have completed a bachelor course, 19 of them had a master's degree and 2 of them were PhD holders. Five of the participants were left-handed, 46 right-handed and 3 did not have a hand preference. Further, 21 of them mentioned a mild eye disorder – i.e., a small degree of myopia or presbyopia –, while 1 of them a major one – Daltonism. Due to the on-line nature of the experiment, the participants were located in different places around the world. Nevertheless, most of them – 43 – were located either in Greece or Cyprus, with their preferred language being Greek. 39 of them were permanent residents of a major city, while 4 of them resided in a smaller city or village. The rest – 11 – were native English speakers from different places around the world. Regarding their profession, 5 of them were working in the public sector, 24 of them were working in the private sector, 7 of them were freelancers, or they had their own business, 5 of them were Students or PhD candidates, 2 of them were retired, and 11 of them were unemployed. Lastly, 52 of them did not mention any brain/mental illness. The experiment included challenging tasks for people with major brain/mental illness or eye disorders. For this reason, such participants were excluded to avoid misleading conclusions. All participants provided written informed consent for their participation and the manipulation of their data.

Chapter 3
Results

3.1 Variables and Preprocessing

The variables extracted and used for further analysis, for all different conditions of each task, were response accuracy [RA] and mean response time [mRT]. A summary of the different conditions can be seen in Table 2. *noGo* condition of the Go/noGo task was the only one which had only the RA variable and not the mRT, as the correct answer of this condition is to not respond. RA was calculated by subtracting the sum of all correct responses from the total number of trials for each condition independently. Similarly, mRT was calculated by averaging the RT of all correct responses for each condition.

It is typical in such experiments to do a preprocessing in the data. Firstly, to minimize unwanted noise, the only participants kept for further analysis were the ones whose Z-Score in RA in all conditions were between -3 and 3 standard deviations [STDs]. Secondly, the tasks had different RT ranges, therefore they were normalized, to be comparable. In particular, DoTIBO and Navon RT trials were divided by 2, Go/noGo RT trials by 0.45 and Stroop RT trials by 1.5, which was the maximum possible duration for reacting in ms. Lastly, all RT trials, with Z-Score exceeding -3 or 3 STDs were marked as outliers, and they were excluded from the averaging process.

3.2 Descriptive Analysis

The normality and the sphericity of the RA and the mRT were inspected, across the different conditions, to examine the characteristics of the data and decide which statistical methods would be better suited. A graphical representation of the distribution of these metrics (Figure 5) displayed that the distributions for most conditions appear to have a normal form. A more detailed analysis revealed that the RA in the *TH-A.TAX*, *Th-A.UNR*, *TAX.UNR*, *Go*, *noGo*, *Unrelated* and *Incongruent* conditions did not follow a normal distribution. Regarding the mRT variable, it did not follow a normal distribution only in the *Global* condition from Navon task. Table 2 provides a detailed report of the metrics for all conditions, including their mean, median, STD, skew, kurtosis and p-val of their normality. Lastly, the sphericity was not violated regarding neither the RA nor the mRT variables. However, because the metrics for some conditions were not normally distributed, the Kruskal-Wallis H-test was used, which is a non-parametric version of ANOVA. For pairwise comparisons, the Games-Howell post-hoc test was used, as it is more robust to heterogeneity of variances. The correlations were calculated using the Spearman method, which seemed to be a more suitable choice for this acquired dataset, as it can handle better non-linear data.

3.3 Per Task Analysis

Before proceeding to combined analyses, it was important to assess each task independently for ensuring that their validity is high. Firstly, comparisons in the responses of DoTIBO, Navon and Stroop tasks' conditions were performed using an H-test. If a significant difference in the H-test was found, a post-hoc pairwise Games-Howell comparison was held to find which conditions have a significant difference. The conditions of the Go/noGo task were compared directly with the Games-Howell test, as it had less than three conditions. Then, the correlation between the RA and mRT were examined, as a negative correlation – speed—accuracy trade-off – is typical between these two variables.

3.3.1 DoTIBO Task

In the DoTIBO task, the responses to conditions involving TH+A were in average more accurate than to the rest (*TH+A.TH-A*:76%, *TH+A.TAX*:80%, *TH+A.UNR*:78%, *TH-A.TAX*:69%, *TH-A.UNR*:71%, *UNR.TAX*:74%), which is something expected. Nonetheless, no significant difference was found by the H-test regarding RA. On the other hand, mRT exhibited a significant difference between conditions involving TH+A and the rest conditions in the H-test ($H=55.095$, $p<0.001$). As anticipated, all TH+A conditions were generally answered faster than those not involving a TH+A object relation. Table 3b provides a complete view of the post-hoc test results.

All conditions showed a significant negative correlation between RA and mRT. In particular, *TH+A.TH-A* ($r=-0.512$, $p<0.001$), *TH-A.TAX* ($r=-0.743$, $p<0.001$), *TH-A.UNR* ($r=-0.753$, $p<0.001$) and *TAX.UNR* ($r=-0.712$, $p<0.001$) had a highly strong negative correlation, while *TH+A.TAX* ($r=-0.434$, $p<0.01$) and *TH+A.UNR* ($r=-0.424$, $p<0.01$) had a strong negative correlation.

Figure 5: Graphical representation of the distributions of response accuracy and mean response time of all conditions.

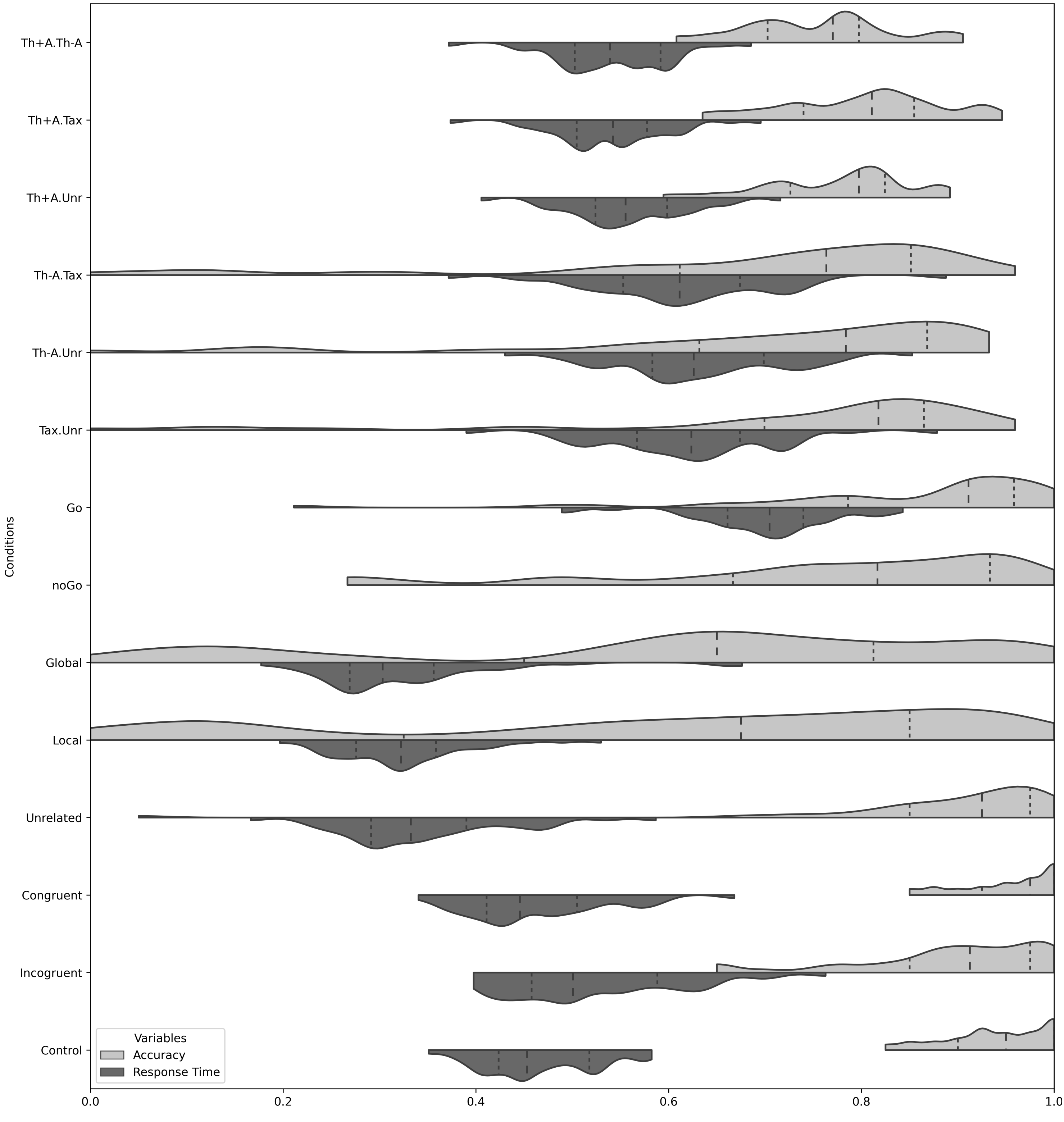


Table 2: Descriptive analytics of each condition.

Task	Condition	mean	median	std	skew	kurtosis	normal	pval
DoTIBO	TH+A.TH-A	0.756	0.77	0.078	0.111	-0.537	×	0.68
	TH+A.TAX	0.801	0.811	0.083	-0.231	-0.638	×	0.531
	TH+A.UNR	0.777	0.797	0.072	-0.539	-0.114	×	0.352
	TH-A.TAX	0.686	0.764	0.244	-1.535	1.604		0.0
	TH-A.UNR	0.711	0.784	0.228	-1.601	2.158		0.0
	TAX.UNR	0.737	0.818	0.227	-1.978	3.379		0.0
Go/noGo	Go	0.853	0.911	0.16	-2.073	5.371		0.0
	noGo	0.756	0.817	0.207	-1.106	0.396		0.015
Navon	Global	0.599	0.65	0.302	-0.642	-0.782	×	0.13
	Local	0.583	0.675	0.32	-0.572	-1.04	×	0.117
	Unrelated	0.893	0.925	0.152	-4.247	22.628		0.0
Stroop	Congruent	0.953	0.975	0.05	-0.804	-0.637	×	0.07
	Incongruent	0.892	0.913	0.099	-1.094	0.573		0.015
	Control	0.94	0.95	0.053	-0.576	-0.662	×	0.2

(a) Response Accuracy.

Task	Condition	mean	median	std	skew	kurtosis	normal	pval
DoTIBO	TH+A.TH-A	0.543	0.539	0.06	-0.192	0.571	×	0.775
	TH+A.TAX	0.539	0.542	0.06	0.054	0.838	×	0.702
	TH+A.UNR	0.559	0.555	0.062	0.146	0.285	×	0.918
	TH-A.TAX	0.614	0.611	0.096	0.096	0.847	×	0.681
	TH-A.UNR	0.633	0.626	0.09	0.145	-0.202	×	0.851
	TAX.UNR	0.621	0.624	0.091	0.155	0.798	×	0.679
Go/noGo	Go	0.699	0.705	0.076	-0.748	1.317	×	0.055
Navon	Global	0.328	0.303	0.1	1.838	4.416		0.0
	Local	0.326	0.322	0.069	0.794	0.929	×	0.075
	Unrelated	0.346	0.333	0.086	0.683	0.462	×	0.189
Stroop	Congruent	0.463	0.446	0.073	0.674	0.109	×	0.211
	Incongruent	0.525	0.501	0.09	0.637	-0.24	×	0.224
	Control	0.467	0.453	0.059	0.231	-0.762	×	0.456

(b) Normalized mean Response Time.

3.3.2 Go/noGo Task

Typically, the most crucial dependent variable of the Go/noGo task is the error rate in the *noGo* condition (Wessel, 2018), which essentially shows the participants' inhibitory control. Error rate can be inferred as one minus RA, if RA is normalized. The relative frequency of unattended trials in *Go* condition can be inferred as the absence rate. If both of them are too low, then it would mean that the test was too easy. On the contrary, a high error rate would mean that the task was too challenging. Hence, the mean error rate was approximately 24%, and it was significant with the absence rate of the *Go* condition (p=0.016), which was approximately 15%. Essentially this is the same as comparing the RA of the *Go* and *noGo* condition as the data were normalized. Furthermore, there was a significant negative correlation between RA and mRT in the *Go* condition (r=-0.354, p=<.05), and a significant positive correlation between the RA in the *noGo* condition and the mRT in the *Go* condition (r=0.379, p=<.0011). These metrics aid in ensuring the reliability of this task, as all of them are in typical boundaries (Hirose et al., 2012).

3.3.3 Navon

The H-test revealed a significant difference in the RA of the *Global*, *Local* and *Unrelated* conditions (H=40.09, p<0.001) in the Navon task. In particular, the Games-Howell test confirmed that there was a significant difference between the *Global* and *Unrelated* (p<0.001) and *Local* and *Unrelated* conditions (p<0.001), in which *Global* and *Local* had lower RA in average than *Unrelated* (60%, 59% and 90% respectively). There was not any significant difference considering the mRT variable. Moreover, there was a significant positive correlation between RA and mRT in the *Local* condition (r=0.574, p<0.001), but no significant correlation was found between them in the other two conditions.

These results were not typical, as a significant difference was expected between the *Global* and *Local* stimuli, their performance was considered too low, and their distribution in Figure 5 seemed highly problematic. For this reason, this task was not taken into further consideration in the discussion. Nevertheless, there were two statistical significant correlations with few DoTIBO's conditions, which are presented in Table 4 for completeness.

3.3.4 Stroop Task

Concerning the Stroop task, a significant difference was found in both RA (H=10.971, p=0.004), and mRT (H=13.295, p=0.001) between the different conditions. More specifically, Games-Howell test indicated a significant difference between the RA to the *Incongruent* and *Congruent* conditions (p=0.001) and *Incongruent* and *Control* conditions (p=0.016), with the *Incongruent* condition having lower RA on average (*Incongruent*:89%, *Congruent*:95%, *Control*:94%). Likewise, mRT had a significant difference between responses to the *Incongruent* and *Congruent* conditions (p=0.002) and *Incongruent* and *Control* (p=0.002), with slower mRT on average in *Incongruent* trials. There was not any significant difference between metrics of the responses to the *Congruent* and *Control*.

A negative correlation was shown between RA and mRT for all conditions. Still, this correlation was significant only in the *Incongruent* condition (r=-0.455, p<0.001).

Lastly, from the *Control* condition we can extract the Stroop interference – *Incongruent* mRT minus *Control* mRT – and the Stroop facilitation – *Control* mRT minus *Congruent* mRT – (Henik & Salo, 2004). The average Stroop interference was approximately 6% and the average Stroop facilitation 2%. The overall results of this task were close to the results found in previous studies (Erdodi et al., 2018).

3.4 Between Tasks comparisons

A comparison between all conditions in both the RA and mRT variables uncovered many significant correlations between DoTIBO and the rest of the tasks.

In the Go/noGo task, the RA in the *Go* condition had a significant positive correlation with the RA of *TH+A.TH-A* (r=0.33, p=0.031), *TH+A.TAX* (r=0.33, p=0.029), *TH-A.TAX* (r=0.4, p=0.007) and *TH-A.UNR* (r=0.32, p=0.037) conditions. Additionally, it showed a significant negative correlation with the mRT of *TH+A.TH-A* (r=-0.37, p=0.014), *TH+A.TAX* (r=-0.3, p=0.049), *TH-A.UNR* (r=-0.32, p=0.037) and *TAX.UNR* (r=-0.31, p=0.041). The RA in the *noGo* condition had a significant positive correlation with the RA in *TH+A.TH-A* (r=0.43, p=0.004) and *TH+A.TAX* (r=0.54, p<0.001).

Regarding the Navon task, the RA in the *Global* condition had a significant positive correlation with the RA in *TH-A.TAX* (r=0.3, p=0.047) and a significant negative correlation with the mRT of *TH+A.TH-A* (r=-0.32, p=0.035). What is more, the mRT in the *Unrelated* condition had a significant positive correlation with the mRT in *TAX.UNR* (r=0.31,

Table 3: p-values of the statistical significant Games-Howell post-hoc pairwise comparisons of per task conditions. * = p<.05, ** = p<.01, *** = p<.001.

Task		Go/noGo	Navon	Stroop	
	Condition	noGo	Unrelated	Congruent	Control
Go/noGo	Go	0.016*			
Navon	Global		<0.001***		
	Local		<0.001***		
Stroop	Incongruent			0.001**	0.016*

(a) Response Accuracy.

Task		DoTIBO			Stroop	
	Condition	TH-A.TAX	TH-A.UNR	TAX.UNR	Congruent	Control
DoTIBO	TH+A.TH-A	0.001**	<0.001***	<0.001***		
	TH+A.TAX	0.001**	<0.001***	<0.001***		
	TH+A.UNR	0.022*	<0.001***	0.005**		
Stroop	Incongruent				0.002**	0.002**

(b) Mean Response Time.

p=0.039).

Finally, in the Stroop task there was a significant positive correlation between the mRT in the *Congruent* condition and the mRT in *TH+A.TH-A* (r=0.41, p=0.005), *TH+A.TAX* (r=0.34, p=0.025), *TH+A.UNR* (r=0.36, p=0.015), *TH-A.TAX* (r=0.32, p=0.036), *TH-A.UNR* (r=0.31, p=0.042). Additionally, there was a significant negative correlation between the mRT in *Incongruent* and the RA in *TH-A.TAX* (r=-0.32, p=0.004) and a significant positive correlation with the mRT in *Incongruent* and the mRT in *TH+A.TH-A* (r=0.54, p<0.001), *TH+A.TAX* (r=0.49, p<0.001), *TH+A.UNR* (r=0.50, p<0.001), *TH-A.TAX* (r=0.42, p=0.005), *TH-A.UNR* (r=0.48, p=0.001) and *TAX.UNR* (r=0.43, p=0.004). Lastly, the mRT in the *Control* condition had a significant negative correlation with the RA in *TH-A.TAX* (r=-0.31, p=0.04) and a significant positive correlation with the mRT in *TH+A.TH-A* (r=0.56, p<0.001), *TH+A.TAX* (r=0.50, p<0.001), *TH+A.UNR* (r=0.49, p<0.001), *TH-A.TAX* (r=0.41, p=0.005), *TH-A.UNR* (r=0.48, p=0.002) and *TAX.UNR* (r=0.40, p=0.008). Finally, no significant correlation was found between the metrics of the responses in any of the DoTIBO conditions and the difference of *Congruent* and *Incongruent* either in RA or mRT, the Stroop interference and the Stroop facilitation. Table 4 indicates all significant correlations.

Table 4: r-values of the statistical significant Spearman correlations. RA: Response Accuracy, mRT: mean Response Time. * = p<.05, ** = p<.01, *** = p<.001.

Task			Go/noGo		Navon		Stroop		
	Variable		RA		RA	mRT	mRT		
		Condition	Go	noGo	Global	Unrelated	Incongruent	Congruent	Control
DoTIBO	RA	TH+A.TH-A	0.33*	0.43**					
		TH+A.TAX	0.33*	0.54***					
		TH-A.TAX	0.40**		0.30*			-0.32*	-0.31*
		TH-A.UNR	0.32*						
	mRT	TH+A.TH-A	-0.37*		-0.32*		0.41**	0.54***	0.56***
		TH+A.TAX	-0.30*				0.34*	0.49***	0.50***
		TH+A.UNR					0.36*	0.50***	0.49***
		TH-A.TAX					0.32*	0.42**	0.41**
		TH-A.UNR	-0.32*				0.31*	0.48**	0.45**
		TAX.UNR	-0.31*			0.31*		0.43**	0.40**

Chapter 4
Discussion

A major part of our cognition is the relations we create between themes, objects and, in general, concepts. Consequently, there is a continuous curiosity from researchers of this field in exploring the underlying structures. Semantic memory is considered the core of functional knowledge in the classical view of cognition, as it holds all information regarding language, symbols, and their relations (Gage & Baars, 2018c). Complementary to this notion, embodied cognition supports that the body and the environment are also parts of our noesis (Shapiro & Spaulding, 2021). Hence, actions and interactions with the objects and situations around us can affect our perception and the cognitive relations we create.

Studies regarding cognitive relations in different age groups have found that children and elderly people tend to prefer TH relations, while adolescents and adults tend to prefer TAX relations (Estes et al., 2011; Lewis et al., 2015; Murphy, 2001). A similar trend has been found in experiments regarding inhibitory control. In particular, Hasher et al. (1991) has demonstrated that children and elders have less inhibitory control than in-between ages. For this reason, we could hypothesize that inhibition might play a role in the way we make cognitive relations. Indeed, numerous studies have investigated the role of inhibition in cognitive relations, and they have found that individuals with poor inhibition tend to prefer TH relations, whereas good inhibitory control leads to the preference of TAX relations (Guest et al., 2016; Mirman et al., 2017). Nonetheless, to our knowledge, no study has examined the role of inhibition in TH+A relations.

In the aforementioned studies, the researchers' goal was to observe the participants' preference over different age groups. For this reason, they did not explicitly ask the participants to seek for a specific type of cognitive relation – TH or TAX –, rather they let them make a choice based on their liking. Such approach is optimal for finding the choice of preference, but not for investigating the participants' ability to recognize a specific cognitive relation. In the current master's dissertation, the participants were explicitly asked to search for the TH+A relations, which practically measures their performance on recognizing such relations. This approach could offer a more precise understanding of the role of inhibition in TH+A relations than a free choice form.

4.1 DoTIBO Task

In our experiment, response accuracy [RA] in the DoTIBO task was higher in all conditions which involved TH+A relations. This demonstrated that most participants successfully recognized TH+A relations. However, this difference was not significant, as in previous studies (Tsagkaridis et al., 2014). This might be due to the restricted response time per trial, which was an extra layer of complexity compared to Tsagkaridis' case, where participants did not have any time limitation. This can be further supported, as overall RA was lower than in Tsagkaridis' experiment.

Significantly less time was required for the recognition of TH+A relations, which can be interpreted as less cognitive effort in recognizing such relations. Previous literature supports that thematic [TH] relations are more automatic than taxonomic [TAX] relations, which demand more cognitive resources (Guest et al., 2016).

Based on this, we can assume that the conditions in which TH relations are absent would be the hardest to recognize. Nonetheless, this is not the case, as TH-A relations can be hard to distinguish from TH+A, and they can lead to the production of many false alarms. This is especially prominent in the *TH-A.TAX* condition, which received the least accurate responses. In this condition, there is the highest interference, because both TH-A and TAX relations are related with the target object, but they lack action, which can be highly confusing and difficult to respond to.

4.2 Go/noGo and DoTIBO Tasks

Concerning the Go/noGo task, the correlations between RA and mean response time [mRT] display the participants' ability in finding a balance in their responses. If they acted too fast, they could loose RA in the *noGo* condition as they would be too impulsive, on the other hand too slow responses could yield many misses in the *Go* condition.

The objective of this master's dissertation was to explore if there are any correlations between poor inhibitory control – i.e., low RA – and the recognition of TH+A relations.

The correlations between the response metrics of the DoTIBO and Go/noGo tasks show some interesting trends. In particular, only the RA in *TH+A.TH-A* and *TH+A.TAX* conditions is correlated with the RA in the *noGo* condition, which suggests that participants with good inhibitory control had better chances in recognizing TH+A relations. Nonetheless, it is interesting to notice that the correlation of the RA in the *TH+A.TAX* condition was stronger than the RA in the *TH+A.TH-A* condition. Additionally, the RA in the *TH+A.UNR* condition is not at all correlated with the RA in the *noGo* condition. For this reason, we can suggest that inhibition does not determine the recognition of TH+A relations, but of the object distractor of the triad. More specifically, it could be that the presence of an object which requires more inhibitory control interferes with the target object, making its recognition more demanding. Thus, poor inhibition could produce poor results in these two conditions because recognition of the opposite object is poor and the response is more random. This is in tandem with this master's dissertation main hypothesis.

The correlation between the RA in the DoTIBO and the *Go* conditions provided some intriguing results too. The RA in nearly all DoTIBO conditions, except *TH+A.UNR* and *TAX.UNR*, is positively correlated with the RA in the *Go* condition. Likewise, the mRT in most DoTIBO conditions is negatively correlated with the RA in the *Go* condition. This implies that the ease of recognizing the correct answer in the DoTIBO task is dependent on the abilities and skills of the participants to successfully accomplish a demanding task, which is also bound to the tools used for this experiment. For example, participants who use their computer in a daily basis might be more skilful in this process of evaluation than others who are unfamiliar with a computer keyboard. This has also been detected in other studies regarding the Go/noGo task (Erickson et al., 2011). Such exogenous factor could interfere with the overall outcome by producing bias.

4.3 Stroop and DoTIBO Tasks

Stroop task assesses the inhibition of automatic responses by comparing the RA and the mRT between the *Congruent* and the *Incongruent* condition. Higher inhibitory control would produce a smaller gap between the *Congruent* and the *Incongruent* condition in both variables, with higher RA and faster mRT in the *Incongruent* condition. Nevertheless, inhibitory control per se can be also evaluated by measuring the RA of the *Incon-*

gruent condition, similar to the *noGo* condition of Go/noGo task. In the current master's dissertation, the outcome of Stroop task was similar to previous studies, with the *Incongruent* condition having on average slower and less accurate results than the *Congruent* and *Control* condition, which had comparable outcomes. Similarly, Stroop facilitation is crucial for detecting the level of the participants' engagement with the task, while Stroop interference captures the participants' difficulty to this task. In this master's dissertation, both Stroop facilitation and interference were fairly low on average, which implies that the participants in general were highly engaged, but they did not find the task so difficult.

Regarding RA of the DoTIBO task, only the *TH-A.TAX* condition was negatively correlated with the mRT of *Congruent* and *Control*. Similar to the *Go* condition of the Go/noGo task, this correlation can be due to the ease some participants might have in such type of experimentation. It is worth noting that this correlation occurred on the *TH-A.TAX*, which is the condition with the maximum interference in the DoTIBO task, implying that the participants who were highly engaged in the Stroop task had better performance in such condition. Thence, engagement and general interest could be a strong factor for the recognition of cognitive relations and especially in overcoming confusing stimuli. Furthermore, the fact that there is no correlation between *TH-A.TAX* and *Incongruent* conditions shows that inhibition might not be involved in the recognition of cognitive relations. Except this result, there is no evidence supporting this master's dissertation hypothesis in the RA variable, as no other correlation between DoTIBO and the *Incongruent* condition was found.

Nearly all conditions of the mRT variable in the DoTIBO task were positively correlated with the mRT of all conditions of the Stroop task. In particular, only the mRT in the *TAX.UNR* and *Incongruent* did not exhibit any correlation. Therefore, we can interpret that the less the engagement, the more time is needed to recognize the cognitive relations, which seems logical. No other meaningful interpretation of the mRT variable can be found which could support the current hypothesis.

4.4 Limitations and Future Work

One of the main concerns regarding this master's dissertation is that there are not many experiments conducted online with Psychopy. The fact that the experiment took place in different environments can be a strong factor for degrading its validity, even though Psychopy is stable and generally yields accurate measurements. Likewise, this master's dissertation included both English and Greek native speakers, which is infrequent in akin studies of the field. For this reason, the repetition of the same experiment in an in-person lab setting would fortify the current results and assess the reliability of conducting experiments online and in a multilingual setting. Along with that, it would be interesting to evaluate if another medium of examination – i.e., the use of analogue objects, responding through voice etc. – would bear different results.

It was observed that a high number of people aborted the experiment before its completion (90) compared to the ones who finished it (54). The experiment's duration was about 45 minutes, and it required a lot of devotion and cognitive effort. This might have affected the results too, as the participants who completed the tasks could have possibly got tired and lost interest and focus. Hence, it would be exciting to re-examine these hypotheses on a more simplified version of the tasks. Similarly, the total number of participants and their sociopolitical background could also be another factor influencing the present outcome, as most participants were females (43) and in general quite educated – 43 were holders of a bachelor's degree or higher. The relatively small variability on the age could further limit the generalization of the current master's dissertation. Lastly, even though the participation level was similar to relative studies, a higher number of participants would generally provide more confidence.

As indicated earlier, Navon task's results were highly problematic. Stoet's (2021) version seem to have major design issues, as the parallel observation of both *Global* and *Local* stimuli confused the participants. The original version, in which there is a serial examination – i.e., first observing the *Global* and then the *Local* – could render higher reliability.

Another limitation comes from the content of the DoTIBO task. Many participants – especially females – mentioned that they could not understand some objects and their relations with the other ones displayed on this task. For example, there were some tools, like the vice, which were too "masculine" based on our current sociopolitical norms. Such objects might not be familiar to a particular group of people because they might never have used them. Similarly, few typical "feminine" objects were present in the task, such as nail polish. TH relations are highly influenced from the sociopolitical environment, and the alteration to more neutral and general thematically related every-day objects could produce less bias.

Chapter 5
Conclusion

The current master's dissertation attempted to investigate the role of inhibition in the detection of thematic relations involving action. This was made possible by testing the inhibition of the participants using three highly popular tasks, namely Go/noGo, Navon and Stroop task, as well as their performance in recognizing thematic relations involving action by using the DoTIBO task. The results between the DoTIBO and the Go/noGo tasks validated that the distractor object could be associated with inhibitory control. No support of the current hypothesis was found in the results of the DoTIBO and the Stroop task. Nonetheless, further investigation is needed to ensure the validity of these results, as few limitations in the design of the experiment were found.

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