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# Look outside the box, to think outside the box: insight, eye movements and solution accuracy

PhD candidate

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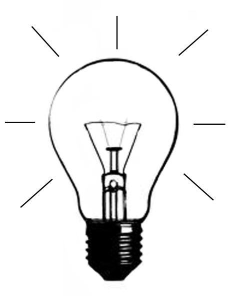

I, Carola Salvi, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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*Dedicated to my family: mom, dad and Bradley.*

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# SUMMARY

Many contributions have been made since Gestalt Psychology introduced the study of insight problem solving. Taking advantage of recent progression in neuroscientific techniques, scientists have supplemented traditional theories with data from newer paradigms. This has meant a leap forward in our knowledge of insight and it has also raised new questions about which cognitive processes are involved.

Based on the most recent neurological model developed by Beeman, Bowden and Kounios (Beeman & Bowden, 2000; Bowden, Jung-Beeman, Fleck, & Kounios, 2005; Kounios, Frymiare, Bowden, Fleck, Subramaniam, Parrish, & Jung-Beeman, 2006; Kounios & Beeman, 2009), the work presented in this thesis investigated how problem solving involves attention and the visual system (Chapter 1). Previous studies demonstrated distinct patterns of neural activity for solving verbal problems via insight compared to analysis, both immediately prior the solutions and in rest periods before the presentation of each problem (Jung-Beeman et al., 2004; Kounios et al., 2006). We examined eye movement and blink patterns associated with the two different problem-solving styles, and in accordance with previous behavioral and neuroimaging research, the patterns have been found to be distinct. Specifically, more frequent and longer-lasting blinks were recorded during the two-second preparatory period before subjects saw problems that they subsequently solved with insight, compared to problems they went on to solve analytically. In the two-second period immediately prior to achieving insight solutions, participants also blinked longer and made more fixations outside the problem area compared to the same period preceding analytical solutions. A follow-up experiment further confirmed these findings, showing a modulation of the incoming bottom-up visual information during the

preparatory period. These results reinforce and supplement previous studies which suggested that insight is related to the attention system, which modulates eye movements and blinking patterns, and also indexes a discrimination of internal *vs*. external directed visual attention between the two solving styles (Kounios & Beeman, 2009; Wegbreit, Suzuki, Grabowecky, Kounios, & Beeman, 2012).

In Chapter 2, new data supplements Beeman, Bowden and Kounios's model by detecting the influence of problem-solving styles on solution accuracy. The data obtained from four different types of problems demonstrated that solutions achieved via insight are more likely to be correct than answers achieved via analysis. Several potential explanations of the result are discussed, foremost the idea that insight depends on the integration of multiple weak associations; i.e., weak associations of problem related info to the solution, which summate boost the activation of the solution concept into consciousness. Thus, when the solution does emerge, it is necessarily correct.

Taken together, these results indicated that insight problem solving is promoted by the gating of visual inputs. This diminishes external noise and directs attention inwardly, to facilitate answer accuracy.

Furthermore, in order to allow the study of insight problem solving in Italy, the Italian language version of two of the most used tasks to study insight problem solving, has been tested and validated. In particular we benchmarked the Compound Remote Associates (CRA) word problems (Bowden & Jung-Beeman, 2003a) and the Rebus Problems (MacGregor & Cunningham, 2008), (Appendix 1).

# INTRODUCTION

*Keep a good head and always carry a light bulb.*

Bob Dylan

Bob Dylan was about ready to give up his career. Yet in a moment of his life marked by increasing frustration, he had the insight that would be a watershed in the history of rock and roll. All-of-a-sudden in the tranquility and isolation of his Woodstock, NY home, the poet-musician overcame his impasse. Grabbing a pen, he frantically filled up his notebook; *"…like a rolling stone"*.

For long time Albert Einstein had been trying to frame space and time into a mathematical model, when accidentally, while he was riding a streetcar home, the Bern's clock tower attracted his attention. At that moment, the idea of combining space and time into a single continuum relative to the velocity of the observer materialized in his mind. Out of that intuition Einstein developed his theory of relativity, forever transforming theoretical physics and astronomy.

Every tale of creativity begins with a problem and culminates with the idea that solves it. It starts with a question, may develop into frustration and perhaps even into a "mental block," until unexpectedly, the solution appears in our mind. Cognitive science defined this type of sudden comprehension as *insight* (Smith & Kounios, 1996; Sternberg & Davidson,

1995) whereas popular imagery depicts it as a suddenly-illuminated light bulb appearing above one's head.

Starting from Archimedes' *Eureka*, through Leonardo, Newton, Mozart, Picasso, Einstein and so on, creative journeys all share a common pattern: after an initial search there is an impasse, and there is no longer a progression toward a solution (Dominowski & Dallob, 1995; Duncker, 1945; Smith, 1995), until the "Aha!" when the light bulb turns on. Insight solutions are experienced by the solver as arising suddenly (Metcalfe & Wiebe, 1987; Smith & Kounios, 1996) with an immediate recognition of the solution's veracity (Jung-Beeman et al., 2004). The way to the problem has been reinterpreted and impasse overcome is usually not reportable (Maier, 1931; Ohlsson, 1992; Schooler & Melcher, 1997) and often solvers are not even aware they are thinking of the problem. Insight problem solving is associated with creative thinking and other cognitive abilities different from those related with performance on noninsight problems (Schooler & Melcher, 1997).

After the pivotal idea, the creative process focuses on the realization of it, which in both Dylan and Einstein's cases entailed the translation of it into a code such as a lyric or mathematical formula. What enables us to switch from impasse to breakthrough? Why does it happen so suddenly? To begin, it seems to be quite common that the pivotal idea arrives during a moment of relaxation, (e.g. Bob Dylan was absorbed in the quiet of Woodstock, or Newton was under the famous apple tree) usually after the solver has stopped searching for it. Does such an oft-described experience of relaxation improve ones' probability of achieving an "Aha!" moment? If so, why? What cognitive processes are enrolled in this kind of problem solving?

My doctoral research contributes to the scientific understanding of insight by detecting the neurocognitive mechanisms that underlie it. In particular, I concentrated on how the vision-system is involved in processing them and what the attentive correlates of this modulation are.

Another focus of this essay is the feeling of veracity that accompanies the pivotal idea. When Archimedes had his famous *Eureka* moment he was reportedly taking a bath. He was so immediately confident in his solution (he figured out how to asses the volume of an irregular object) that on his way to inform King Hero II, he ran nude through the streets proclaiming "*Eureka*!" I wondered if this striking feeling of certainty that accompanies the "Aha!" at all corresponds to an increased accuracy in participant responses. In other words, when we have an insight we also feel strongly that the answer to our dilemma is the right one– is this certainty empirically justifiable? In the second chapter I answer this question by analyzing the accuracy of insight responses of four different problems.

One of the reasons that I spent part of my doctorate program in the United States was the lack of an Italian task with sufficient number of problems to be able to use the techniques (such as eye tracking and priming measures) that can reveal objective correlates of solvers' subjective experiences. Indeed, classic insight problems (those already translated into Italian anyway) are often so difficult that only a small percentage of participants manage to produce a solution within a reasonable amount of time (e.g. less than 10 min) and without at least some assistance (e.g. a hint). Two set of problems that had overcome this hurdle had been tested and developed mostly in English, e.g. Rebus Puzzles (RP) (MacGregor & Cunningham, 2008) and the Compound Remote Associates (CRA) words problems (Bowden & Jung-Beeman, 2003a). To later overcome this problem an

Italian version of Rebus Problems and the CRA word problems I used in the U.S, has been created, tested and validated (Appendix 1).

# THEORETHICAL FRAMEWORK

## The “Aha!” moment

The story of the “Aha!” moment begins with the Gestalt Psychologists in the first quarter of the 20th century. Before them, problem solutions were considered the result of automatic associations through trial-and-error applications of preexisting responses (Thorndike, 1911). In the Gestalt theory of the mind, the solution of a problem instead occurs through productive thinking and goes beyond the old associations the solver has stored, allowing him to see a problem in new ways (Kohler, 1925; Wertheimer, 1945). Whereas associationists had mostly been engaged with dividing stimuli into components, Gestaltists were instead interested in ‘whole’ form (or percepts), defined as “other than the sum of its parts” (Koffka, 1935). They saw a clear connection between human perception and problem solving (Köhler, 1969; Mayer, 1995). Similar to the perspective switch used to explain perceptual organization, solution via insight was described as a sudden and completely new finding in one’s mind, which could be attributed to successful problem reinterpretation. The unexpected nature of insight was a crucial contribution as the behaviorist opposition intended problem solving like a trial-and-error incremental process (Evans, 2005). They considered it as a creative process based on a “sudden restructuring (*Umstruktuierung*) or recentring (Umzentrierung) of the perceptual field” (Kohler, 1929/1947; Wertheimer, 1945/1959). As it happens for visual illusions (e.g the Necker Cube or the Rabbit-duck illusion), during an insight there is an epiphanic shift from one state, where the solvers don’t know how to reach the problem’s goal, to another where they have a deep understanding of it (Maier, 1940). A representative example of it is the description of the “two string problem” given by Maier (1931). It consisted of tying together two strings suspended from the ceiling. The difficulty of the solution consisted in the fact that the strings were placed too far from each other for the participant to reach one while holding the other. The insight came by realizing the possibility of tying an heavy object (e.g. a pair of pliers placed in experiment room) to one string and make it swing as a pendulum. Therefore, the string which is oscillating would become easier to catch whilst holding the other and eventually it would be possible to connect them. Maier first observed that the solution emerged abruptly and all-at-once. In addition, he reported that participants have always been blind to hints given (such as the experimenter brushing against one of the strings and making somehow swinging) although they solved the problem only a few moments later. Maier claimed that this was attributable to the sudden feeling of the solution prevailing consciousness.

Most foci of this thesis were pioneered by Gestalt school. They both established the parallelism between solution via insight and human vision and the idea that insight leads to the right solution. Regarding the latter, intrinsic in the Gestalt’s definition of insight, i.e. being the special moment that allows one to overcome an initial “wrong” representation of the problem, was the assumption that when an insight comes it is correct. As an example, according to the Gestalt theory of mind, only by looking outside the square area of the nine-dot problem (Maier, 1930) and therefore overcoming the functional fixedness (Duncker, 1945), was it possible reach the “solution.” This feature, which seemed obvious for Gestalt’s psychologists, has never been experimentally checked until now.

Gestalt’s theoretical framework established and guided the problem solving theories that followed. Despite their significant contribution however, Gestaltists mostly focused on the conditions that did and did not promote insight, e.g. constraints like functional fixedness (Duncker, 1945), or mechanization (i.e. *Einstellung*; Luchins, 1942), thereby leaving many questions about exactly what insight is and how it occurs unanswered (Davidson, 2003). Later, scholars continued to focus on constraints but by using dated and arbitrarily chosen “insight problems,” most often neglecting any functional definition of the phenomena. The problems used to study insight have been chosen merely because they were selected as insight problems in previous studies (Weisberg, 1995). As a consequence, researchers have been tangled for years in a circular definition of insight – defining it only as the process that allows one to solve “insight problems” as classically defined – effectively preventing any leap forward into an explicative understanding of insight itself (Bowden, Beeman, Fleck & Kounios 2005).

A sustained debate took place about whether insight represented a distinct type of problem-solving, as a mostly unique process involving at least some distinct cognitive mechanisms, or whether insight was merely an epiphenomenon based on the same cognitive mechanisms as noninsight solutions (Bowden et al., 2005). The former largely characterized the “Special- Process” view (Sternberg & Davidson, 1995) and the latter the “Business as Usual” view (Perkins, 1998; Weisberg & Alba, 1981). On one hand, scholars of the “Special- Process” view proposed a *representational-change theory* where insight was due to the reinterpretation, or re-reinterpretation, of the problem by relaxing self-imposed limitations and/or decomposing chunked parts of it (Knoblich, Ohlsson, & Raney, 2001; Knoblich, Ohlsson, Haider, & Rhenius, 1999). On the other hand, those who endorsed the ‘Business-as-Usual’ view proposed a *progress-monitoring theory*

(MacGregor, Ormerod, & Chronicle, 2001) where solvers analyzed the distance from their current state to the goal state and tried to minimize the difference between these two states. In this second theory, insight occurs only when the solver realizes that the distance to the goal cannot be attained with the current approach, so a new one has to be sought. Therefore, insight takes place when a new move is selected which brings the goal within a solvers' capacity to look ahead from the current state to the goal state (Chronicle, MacGregor, & Ormerod, 2004). Despite the different schools of thought, it was quite agreed that: insight solutions are experienced as sudden and feel correct (the "Aha!"); when no longer progressing towards a solution prior to producing an insight solution solvers sometimes come to an impasse; the process that enables one to overcome an impasse and reach a solution is not reportable by the solvers (Schooler & Melcher, 1997; Smith, Ward, & Finke, 1995; Sternberg & Davidson, 1995).

It is clear how these theories focused on different components of the insight process preventing any comparison of their predictions (Bowden et al., 2005). For decades the study of the "Aha!" moment has been cumbered by the assumption that "insight problems" always produce insight solutions, legitimating the use of small numbers of problems to detect it. This was more a tautology than an operational definition of insight. To define insight as the process which allows one to solve a particular category of problems classically considered "insight problems" (i.e. the nine-dot problem; Maier, 1931) defined it from how the "world" has been classified by scholars (insight *vs* noninsight problems dichotomy) assuming that cognitive processes followed any such classification. This precluded any comparison of competing theories thereby restricting the understanding of the processes involved (Bowden et al., 2005). Moreover, insight problems do not even represent a homogeneous class of problems as each differs from the other in involving some specific cognitive operation (e.g. working-memory demands or size of problem space). This way to study insight was extremely difficult to approach through neuroscience techniques. Indeed, classic insight problems were often too complex to be solved by a consistent percentage of participants without some hints or within an amount of time manageable for running studies with neuroimaging or electroencephalograms. Even when many trials of the same kind of problem were used (Knoblich et al., 2001), it was rare to have a sufficient number of problems that did not limit both the reliability of data and the variety of techniques that could be used (Bowden et al., 2005). A pivotal advance in the study of insight problem solving happened when a larger set of problems, useful for neuroimaging studies was created.

## New approaches for demystifying insight

*New set of problems*

A new framework for approaching insight studies overcame many of the difficulties described above. First, only sets of multiple problems which are more useful for neuroscientific experiments, were considered and created for experiments– e.g. Compound Remote Associates (CRA) problems (Bowden & Jung-Beeman, 2003a), Rebus Puzzles (MacGregor & Cunningham, 2008), Anagrams (e.g. Bowden, 1997; Dougal & Schooler, 2007; Kounios et al., 2008), and degrading of real-world pictures (such as Ludmer, Dudai, & Rubin, 2011). These problems all present the following benefits:

i) they have a large pool of trials, at least enough to reach a consistent percentage of success to be used for statistical analysis;

ii) they can be solved in a short time, so that several can be used in a single experimental session;

iii) they have unambiguous solutions, making scoring of responses easier;

iv) they are short and manageable to be quickly presented in on a computer screen.

All features that permit the use an assortment of paradigms (e.g. priming, solution recognition, hemispheric-difference paradigms, and neuroimaging) (Bowden et al., 2005). In the CRA (Bowden & Jung-Beeman, 2003a) for instance, problems patterned after items in the Remote Associates Test (RAT) developed by Mednick, (1962), consist of three problem words (*crab, pine, sauce*) where the participants have to come up with a solution word (*apple*) that can form a compound word or common two-word phrase with each problem word (*crab apple, pineapple, apple sauce*).

*Self reports and solution type differences*

The second fundamental change introduced was to start using self reports to determinate if insight had occurred or not. Scholars evidenced (Metcalfe & Wiebe, 1987; Metcalfe, 1986) solvers' reliability in predicting whether they will eventually achieve solutions of noninsight or insight problems by rating the feeling of warmth when they were approaching the solution. Warmth was used as a measure of how close one felt to reaching a solution. The patterns-of-warmth ratings established that subjects' feelings of approaching solution differ for insight and noninsight problems (Metcalfe & Wiebe, 1987). Specifically, the attempts to solve noninsight problems were associated with a gradual warmth rating, whereas insight solutions had no change in warmth until immediately before reaching a solution. By tracking the warmth rating trend during the solution process, Metcalfe (1986) found that problems solved by a sudden pattern were more likely to be correct compared to those solved incrementally. Metcalfe interpreted the higher rate of errors made using the analytical strategy due to participants relying on the use of a "*successive approximations strategy*."

A further step was the demonstration that participants' self-reports of solution type were correlated with objective measures, behavior, and of brain activity. For instance, participants showed different patterns of semantic priming when recognizing solutions that evoked a subjective insight feeling and those that did not (Bowden & Jung-Beeman, 2003b). Distinct neural correlates were found when participants reported solving a problem with insight versus when they reported solving a problem via analysis, (Jung-Beeman et al., 2004; Kounios et al., 2006; Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009). The latter was mostly used to name noninsight solutions, i.e. an unsurprising systematic process where the solution is achieved gradually and is needs to be verified by the solver, where the intermediate steps are known, and the strategy used is reportable (Ericsson & Simon, 1993; Metcalfe & Wiebe, 1987; Metcalfe, 1986; Newell & Simon, 1972). These studies aided in approaching insight as a method by which people can solve a problem, and not a type of problem in-and-of itself (Bowden et al., 2005) that evokes an "Aha!" experience as in most of the past researches. In the studies just described, it was then demonstrated how solvers subjectively experience such problems differently than they would for noninsight problems. For the reasons I have just described, in the following experiments we embraced this approach and therefore used problems that might evoke both insight or noninsight in my studies.

*Neurological model*

The *modus operandi* described above recognizes the potentiality for either solution method in any given problem allowed for a larger, less complex set of problems to be developed. This enabled a cognitive model (Bowden et al., 2005; Bowden & Jung-Beeman, 2006; Jung-Beeman et al., 2004) to be developed based on behavioral (Beeman & Bowden, 2000; Bowden & Jung-Beeman, 2003a) and neuroimaging (Jung-Beeman et al., 2004; Kounios et al., 2006) studies.

The model considers problem solving in general as a process that involves many cognitive functions, some of which are specific to insight (Bowden & Jung-Beeman, 2007). Bowden and Jung-Beeman (1998; 2003b) first discovered that there is more insight solution priming for solutions presented to the left visual field-RH (lvf-RH) than for solutions presented to the right visual field-LH (rvf-LH). These results tied the subjective experience of insight to an objective measure — semantic priming — and suggested that the "Aha!" experience is more likely to involve the right hemisphere (RH) than in the left one (LH). Thorough studies, using functional magnetic resonance imaging (fMRI) (Jung-Beeman et al., 2004), they confirmed an increased activity in the right hemisphere and located other activities unique to insight solutions in the anterior superior temporal gyrus (aSTG). The EEG data revealed a sudden burst of high-frequency (i.e. 40-Hertz gamma-band) neural activity in the same area beginning 0.3s prior to insight solutions. Linguistic studies demonstrated RH is particularly important for recognizing distant semantic relation between words, and bilateral aSTG is involved in semantic integration (Bowden & Beeman, 1998; Beeman & Chiarello,1997; Beeman, Bowdrn & Gernsbacher, 2000; Jung-Beeman, 2005). This activation during insight solution established that connections across distantly-related information foster this process, allowing solvers to see associations that would have been normally dodged (Bowden & Jung-Beeman, 2003b; Jung-Beeman et al., 2004). Furthermore, about 1.5s before insight solutions – immediately prior the gamma-band EEG activity – there was a sudden increase in power in the alpha-band frequency (10 Hertz), suggesting a decrease in neural activity over right visual cortex (Jung-Beeman et al., 2004). This result demonstrated an involvement of the visual system in discriminating between insight and noninsight solutions. Specifically, it suggested a selective gating of visual inputs to facilitate the immediate subsequent aSTG activation of the right hemisphere. Kounios and Beeman (2009) read the burst of alpha band as the brain's covert alternative of "closing the eyes" or "looking away."

Everyone has noticed that when one is asked a difficult question, they often look away from their interlocutor, or even close their eyes to avoid distractions and concentrate more. This moment is well captured by August Rodin's sculpture *The Thinker* (1902). This tendency was strongly discouraged in Jung-Beeman's et al., (2004) EEG experiment because participants had to keep their eyes open to minimize electrical noise from eyes and blinks. As Tsubota, Kwong, Lee, Nakamura, & Cheng, (1999) shown the visual cortex activation is greater with voluntary blink inhibition. This restriction probably led a sort of covert compensation to reduce the amount of visual information passed from visual areas to higher areas that perform more abstract computation (Kounios & Beeman, 2009; Payne & Kounios, 2009). Overall, the alpha and gamma effects suggest a transitory decrease of interfering visual inputs facilitates the sorting-out of the weakly-activated information necessary to process problem solution by the aSTG.

Besides the alpha "brain blink" effect, insight neural correlate differentiations have been found farther back in the solution timeframe, even before each problem was presented to participants. Kounios et al., (2006) found a selective pattern of brain activity that primes solution via insight or via analysis. EEG recorded greater activity over the midfrontal cortex (i.e. anterior cingulate cortex, ACC) before the presentation of problems to be solved via insight and over the visual cortex before the presentation of problems to be solved via analysis. A similar result was provided by fMRI measurement. Indeed, the ACC is shown to be engaged in cognitive control of attention (Kerns et al., 2004) and in modulating the attentional focus to attend to global *vs*. local spatial extents (Weissman, Gopalakrishnan, Hazlett, & Woldorff, 2005). This suggested that ACC might be involved in the readiness to discern weakly-activated integrated non-conscious concepts and to shift attention to them when they are detected (Kounios & Beeman, 2009). This interpretation is also supported by previous studies which have shown ACC to be involved in error detection (Dehaene, Posner, & Tucker, 1994), suppression of irrelevant thoughts (Anderson et al., 2004; Wyland, Kelley, Macrae, Gordon, & Heatherton, 2003), attention shift (Davis et al., 2005; Dreisbach & Goschke, 2004; Kondo, Osaka, & Osaka, 2004) and selection for competing responses (Badre & Wagner, 2004; Botvinick, Cohen, & Carter, 2004; Kerns et al., 2004; Miller & Cohen, 2001). Moreover, activity degrees in the ACC may indicate readiness levels of participants in detecting and switching attention to less frequent conceptual associates, if the most salient associate is not the solution (Subramaniam et al., 2009). Reversely, the greater neural activity found over the visual cortex – preceding problems solved analytically – suggested that participants are pre-oriented to elaborate visual information thus more prone to direct their attention outwardly (Kounios et al., 2006;

Kounios & Beeman, 2009). This perspective is consistent with the more general idea that creative thinkers have the ability to change cognitive states between defocused and focused attention (Martindale, 1995), strategically inhibit peripheral information when necessary (Stavridou & Furnham, 1996), and allocate attention in a diffuse manner (Dykes & McGhie, 1976). Therefore, the method by which people solve the problem could be affect by their preparatory attentional state.

To summarize, the new approach solves many limitations of the previous one, enables researchers of problem solving to define insight and noninsight as two distinct problem-solving styles related to different neural activities and not defined by the problem itself. The neurological model evinced from it raises many hypothesis which must still be further investigated. For instance, the overall frame shows that insight problem solving involves the visual system in a different way compared to solutions achieved via analysis. In the first and second experiments of Chapter 1, the model is specifically tested in seeking eye movement and behavioral correspondences of the neurological data.

In addition, this theoretical framework suggests a difference in accuracy between the two solving types that seemed to have been neglected until now. The ACC pre-activation (Kounios et al., 2006) suggested this area to have a role of top-down pre-filtering specific to insight solutions, suppressing extraneous thoughts, monitoring competing solutions, and detecting the best solution candidate. As accuracy rates in relation to solution styles fell outside the purview of their studies, the accuracy discrepancy has only been briefly discussed in previous works (Kounios, Fleck, Green, Payne, Stevenson, Bowden, &

Jung-Beeman, 2008; Metcalfe, 1986) and has never been specifically investigated by itself. I address it in Chapter 2 of this essay.

EXPERIMENTAL DATA

## 1. Visual and attention systems when people solve verbal problems with insight

The phrase "think outside the box" is popularly used as an encouragement to "look" for problem solutions outside of the solver's usual thinking patterns, reinterpreting the situation in a new light. Scientists called this kind of understanding *insight*, defined as a sudden emergence of the solution into awareness experienced as absent of conscious processing (Metcalfe & Wiebe, 1987; Smith & Kounios, 1996; Sternberg & Davidson, 1995). The neurological model developed from these studies supports the idea of insight as a sudden switch from the prepotent associations solvers initially focus on, to the weakly-activated representations. This function is mostly due to the ACC's role in attention switching and in detecting the competing solution candidates (Beeman & Bowden, 2000; Botvinick et al., 2004; Bowden & Jung-Beeman, 2003b; Kounios et al., 2006; Kounios & Beeman, 2009; Subramaniam et al., 2009). The neural activity data suggests that attention is involved, specifically, that this switch is facilitated by decreasing the elaboration of external environmental stimuli in favor of internal processing. Wood and Hassett (1983) for instance, proved that internally directed attention yields higher blink rates during problem solving. Until now however, there haven't been any studies that directly investigate the relation between blink rates and insight problem solving. While other studies in the similar field of mind wondering (such as Smilek, Carriere, & Cheyne, 2010), demonstrated that internal processes are modulated by attention allocation, and are associated with higher blink rates and a lower number of fixations, there is a lack of same direct visual evidences in insight problem solving field. The studies that introduced attention as a pivotal modulator of insight solutions were mostly based on neurological and behavioral data. The current experiment, aims to make a further contribution to this prospective using a technique of research, like eye tracking, specifically oriented to detect visual attention allocation.

The tight coupling of oculomotor processes and attentional control have already been demonstrated by several psychophysical, neuroimaging and electrophysiological studies, e.g. psychophysical evidence that focal attention is a needed precursor for preparing eye movements (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; McPeek, Maljkovic, & Nakayama, 1999; Shepherd, Findlay, & Hockey, 1986). For instance the pre-motor theory of attention (Rizzolatti, Riggio, Dascola, & Umiltá, 1987) suggests that eye movements and attentional shifts are driven by the same internal mechanisms.

**Where do we look when we think?**

It is easy to observe that when people think, are mind wondering, or are even just engaged in a conversation, they often avert their gaze to a white wall or some corner of the room, activity popularly understood as methods to disengage from distractors. Studies of gaze aversion have shown that looking “away” facilitates remembering and improves accuracy for questions of moderate difficulty (Glenberg, Schroeder, & Robertson, 1998).

A recent study about mind wandering while reading, (Reichle, Reineberg, & Schooler, 2010) established that fixations pattern, resulting from on-line cognitive processing, is a valid index of mindless reading. Specifically, during the interval immediately preceding mind wandering, participants were more likely to be looking somewhere other than the text and to elongate their fixations. We hypothesized that problems solved via insight to have a similar eye pattern which is decoupled from the visual stimuli as in mind wondering. This prediction is supported by traits the two processes share: the conceptual manipulation of semantic information (Binder et al., 1999) and diminished external accuracy awareness from switching attention inwardly for internal processing.

In the following studies we hypothesized that such a switch of attention allocation is also reflected by eye blinks and eye movements' patterns in order to block external input at the sensory endings. The Experiment 1.1 tested this hypothesis by recording eye movements patterns, and based on the results in the neurological model, we focused the analysis on two specific moments of the solution process: the preparation and the solution periods (respectively two seconds before the problem was presented and two seconds before participants achieve the solution). In Experiment 1.2 we tested the hypothesis of insight being facilitated by gating visual information in directly asking participants to close their eyes.

## Experiment 1.1

### – Looking outside the box to think outside the box: blinks and eye movements associated with insight versus analytic problem solving

*"What I give form to in daylight is only one percent of what I have seen in darkness."*

M. C. Escher

**"Looking" for the solution in a blink**

Blinking, controlled by the orbito-frontal and visual cortexes (Tsubota et al., 1999), physically blocks incoming information by the closing the eyelid, and generates a suppression of vision associated with an inhibitory signal sent out by the brain (Volkmann, Riggs, & Moore, 1980), both before and after eyes close (Bristow, Frith, & Rees, 2005; Bristow, Haynes, Sylvester, Frith, & Rees, 2005; Stevenson, Volkmann, Kelly, & Riggs, 1986; Volkmann, 1986). But as it has been established as consistently related with internal thought processes (Ehrlichman & Micic, 2012), a blink is something more than a mere visual interruption. For example, it has recently been demonstrated that higher numbers of blinks are associated with mind wondering (Smilek, Carriere, & Cheyne, 2010), errors in vigilance related to external stimuli (Papadelis et al., 2007; Van Orden, Jung, & Makeig, 2000), and conflicts between internal and external workloads (Recarte, Pérez, Conchillo, & Nunes, 2008). Again, according Holland and Tarlow (1975), blinking occurs at the moment of cognitive change as an indicant of transitions between different gazes, sets, or ideas. Reversely, blink rate and duration declines when people are involved in processes similar to analysis, which require more intense mental workload (Brookings, Wilson, & Swain, 1996; Hankins & Wilson, 1998; Veltman & Gaillard, 1998), task focusing, and when information in memory is being operated on (Telford & Thompson, 1933) – such as solving arithmetic problems (Holland & Tarlow, 1975). These studies reflect most of the features that distinguish insight and analytical solutions, allowing us to predict higher blink rates for insight solutions and lower rates for analytical ones. Blinking is suggested to be a sensory ending of a top-down order to allow or facilitate an internal and more complex cognitive mechanism that involves attention. Eye blinks have been consistently associated with attention (Poulton & Gregory, 1952). Indeed, recent studies suggest that visual attention disengages from its locus across an eye blink and that blink planning and programming alone is enough to cause it (Higgins, Irwin, Wang, & Thomas, 2009; Irwin, 2011). More importantly, internally-directed attention has been found to yield higher eye blink rates (Wood & Hassett, 1983). All of these results support our idea that reducing the amount of visual information facilitates a balance shift in processing from external stimuli to internal attention– which we hypothesized modulates the problem solving style adopted.

Overall, this study aims to further demonstrate that solutions via insight involve different cognitive mechanisms from those achieved via analysis, mostly due to a different attention allocation. To test this eye blinks and eye movements have been tracked during solution of CRA word problems (Bowden & Jung-Beeman, 2003a). We hypothesized that insights are associated with eye patterns that avoid visual stimuli in order to modulate trade-offs between problem solving and external task-related stimuli. We predicted that, because of different attention allocation, differences found in occipital cortex activity (Jung-Beeman et al., 2004; Kounios et al., 2006) across insight and analysis solutions would be consistent with patterns of eye movements– the former oriented in gating of visual inputs and the latter involved in the stimuli inspection. Three different time windows were selected to analyze the data: The two seconds preceding the appearance of the problem on the screen and the first and final two seconds of the solution process. Consistent with previous results, insight solutions are expected to be predicted by eye movements, and eye blink patterns oriented to reduce the processing of external inputs only for the preparation and the final solution period.

**Method**

*Participants*

Twenty-one Northwestern University students (age M 18.52; SD 0.67, 11 females), with normal or corrected to normal vision, skilled readers, right-handed and native speakers of American English, were asked to solve 120 CRAs word problems and to report whether they solved them by insight or by analysis.

*Stimuli and apparatus*

Each CRA world problem (Bowden & Jung-Beeman, 2003a; Mednick, 1962) consisted of a simultaneous presention of three stimulus words (e.g., *crab, pine, sauce*), to reach the solution, solvers had to think of one additional word (*apple*) that can form a common compound word or familiar two-word phrase with each of the three problem words (*crabapple, pineapple, applesauce*). CRAs can be solved with an insight or analytically. Self-reports differentiating between insight and analytic solving have demonstrated reliability in numerous behavioral and neuroimaging studies (Bowden & Jung-Beeman, 2007; Jung-Beeman et al., 2004; Subramaniam et al., 2009). Stimuli were viewed binocularly: the problem words were written in black on a white background and displayed in 28-pt Times New Roman, with each character subtending 0.34°x 0.40° of visual angle. The three CRA's words were presented in the standard horizontal orientation one above, one at, and one below the center of the monitor, separated vertically by 1.36° of empty space. Each participant sat with their head positioned on a chinrest at a distance of 84 cm from the screen.

*Procedure*

Participants were informed that they would have to read the three words and to come up with the solution word within a 15 seconds time limit. Prior to the experiment three practice CRA problems and instructions regarding how to distinguish insight from analytic problem solving were given. Participants were informed that no solving style was any better or any worse than the other and there were no right or wrong answers in reporting them as insight or analytic.

Eye movements were recorded throughout the trial. After a successful nine-point calibration procedure, trials were presented in a random order. Each trial began with a central fixation cross lasting one second, followed by a response prompt screen. Once participants were ready, they had to press the gamepad button for the fixation cross to appear for another second, and then the three problem words were presented simultaneously on the screen. Following the production of a solution, or at the expiration of the time limit, the problem words were cleared. Immediately afterward, subjects had to report whether they solved it via insight or via analysis. No feedback was given to the participants regarding whether the solution they provided was accurate or inaccurate. Eye position calibration was checked every forty trials to reduce possible eye position measurements' errors due to subjects repositioning movements. In total the experiment lasted approximately 1 hour.

All stimuli were presented on a 19-in. View- Sonic E90FB CRT monitor driven at 75 Hz with a 1024 x 768 pixels resolution, subtending 22.75° x 17.07°. Eyelink Experiment Builder software (SR Research) was used to program the experiment, present stimuli, and to record responses. We used the manufacturer's software for calibration, validation, drift-correction, and computation of eye movement parameters (blinks, saccades, and fixations). A blink was defined as a period in which a pupil was not detected by the Eyelink software. An eye movement was classified as a saccade when its length exceeded 0.2º and its velocity 30º/sec, or when its length exceeded 0.2º and its acceleration 9,500º/sec. Fixations were defined as any period that was not classified either as a blink or as a saccade.

*Data analysis*

Eye blinks and fixations were analyzed across the two solutions styles during the preparation period (i.e., two seconds before the problem appeared on the screen), the onset period (i.e., two seconds after the problem appeared on the screen), and solution period (i.e., two seconds before the solution button was pressed) (see Figure 1, section A for details). Overall participants solved correctly 39% (M 47.76; SD 8.7) of problems given. Because considered immediate recognition rather than problem solving, only problems solved in more than two seconds (96%; M 44.9; SD 8.8 of those solved in the whole period) were considered for the preparation period. 60% (M 25.95; SD 5.31) of correct solutions were labeled as insight (average response time: 5.31s, SD 1.04) and 40% (M 17.95; SD 17.95) as analysis (average response time: 8.30s, SD 1.68).

To avoid any overlapping within onset and solution periods, only problems correctly solved in more than four seconds (67.7% of those solved in the whole period; M 31.6 SD 6.1 on 120 given) were considered in the onset-solution periods analysis. 49.7% (M 15.7; SD 6.4) of them were labeled as insight (average response time: 6.53s, SD 1.71) and 50.3% (M 15.9; SD 6.5) as analysis (average response time 8.16s, SD 2.24). Because of miscalibration problems four participants were removed from the interest areas analyses. Participants outside of M±2.5 SD solution rate for each style were discarded. In the eye blink analysis subjects outside of M±2.5 SD number of trials containing at least one blink for each style in the selected time windows were also discarded.

**Results**

The visual inspection of the **preparation period** shows that insight solutions were predicted by a significantly (two-tails t-test, $t(20) = 4.94$, $p < .000$) higher number (insight M 0.84; SD 0.49; analysis M 0.69; SD 0.47) of blinks, which also lasted longer (two-tails t-test, $t(20) = 2.63$, $p < .05$) (see Figure 1, section B for details). Because the blink variable is discontinuous, the number of trials containing at least one blink was also analyzed. Consistently, insight solutions were predicted by a significant higher (two-tails t-test, $t(20) = 3.40$, $p < .005$) percentage of trials containing at least one blink (insight M 65.1 %; SD 28.30; analysis M 56.8%; SD 32.64). The reported data is confirmed by significant increase (two-tails t-test, $t(20) = 2.54$, $p < .05$) of pupil size change for problems solved via insight (average of: pupil max diameter – pupil min diameter for each trial; insight M 1892 units; SD 903; analysis M 1722 units; SD 937) as an evidence of pupil mydriasis triggered by blinking. Moreover, pupil size changed positively correlated with the number of blinks ($r = 0.65$, $p < .005$; Pearson's bivariate correlation). Moreover, subjects made more fixations prior to analytic solutions rather than insight solutions (one tail t-test, $t(20) = -1.84$, $p < .05$).

The eye movement data of the **solution period** shows a significant increase in blink duration (two-tails t-test, $t(18) = 2.37$, $p < .05$) for problems solved via insight, and a higher number of fixations (two-tails t-test, $t(18) = -2.62$, $p < .05$) for those solved via analysis. No significant differences were found during the **onset period** (see Figure 1, section B and C).

A set of separate analyses further detected eye movements inside the problem area (i.e., the region that includes the problem words, also called the "box"; white colored in Figure 1 section D), and in the area surrounding the problem (i.e., the region around the problem words, also called "outside the box"; blue colored in Figure 1 section D) during the solution period. The data demonstrated that the number of fixations inside the problem area decreased significantly (two-tails t-test, $t(16) = 2.24$, $p < .05$) for problems solved via insight compared to those solved via analysis. Reversely, insight solutions were associated with a lower number of fixations in the area surrounding the problem (one-tail t-test, $t(16) = 1.76$, $p < .01$). A 2 x 2 ANOVA showed a significant interaction between inside/outside problem areas and insight/analysis solutions ($F(1,15) = 6.91$, $p < .05$).

Additionally, the analysis of the overall dwell time spent outside the box is significantly higher for problems solved via insight ($t(16) = 2.16$, $p < .05$) (insight M 122.6 msec; SD 124.3; analysis M 80.14 msec; SD 68.4).

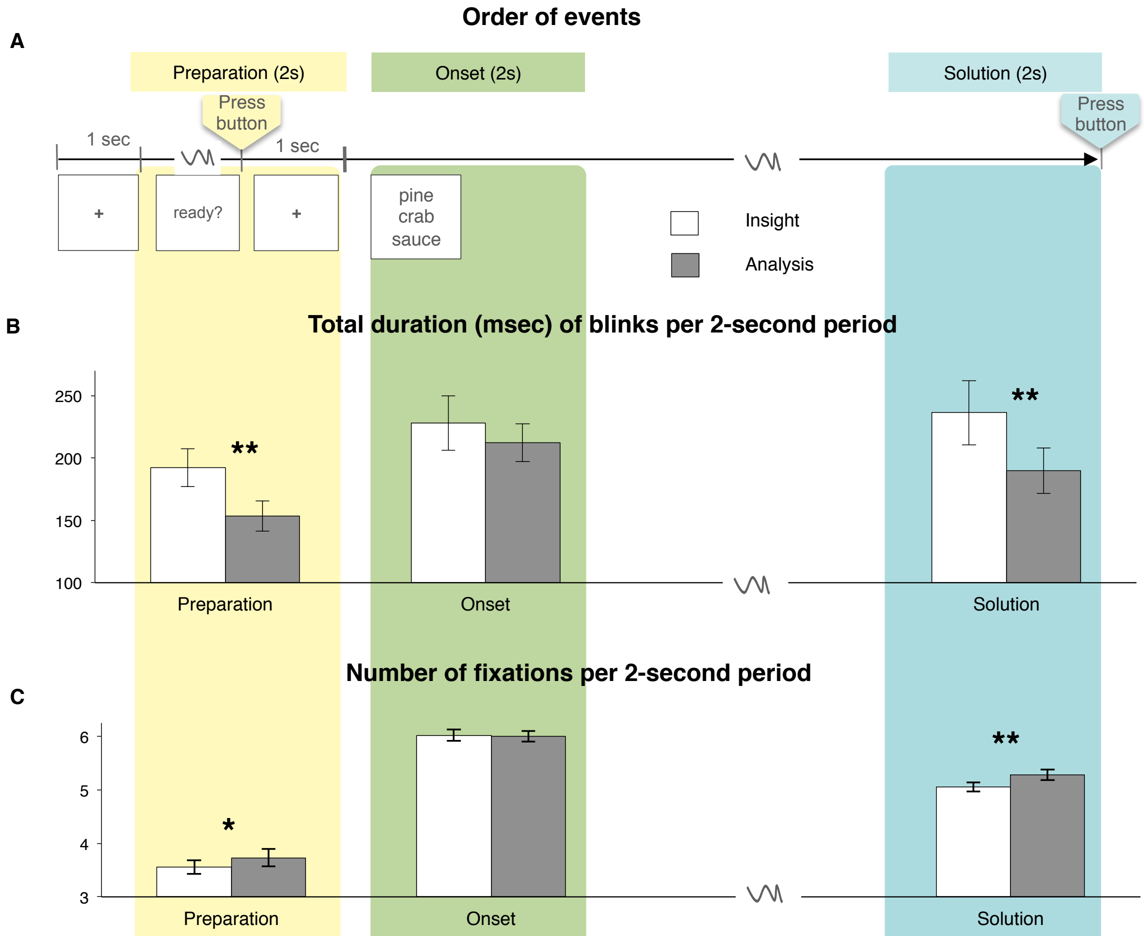
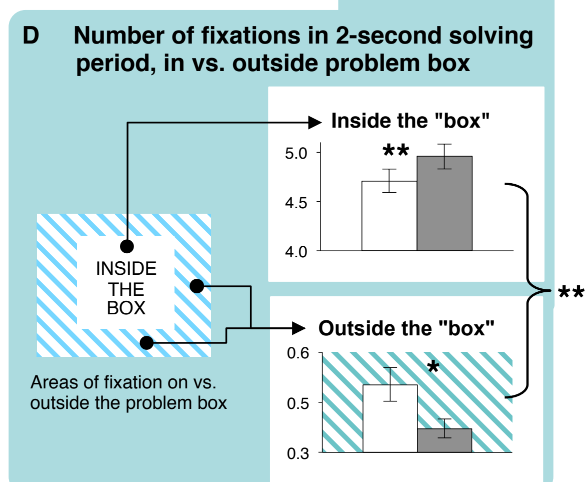



*Figure 1:* **A.** Each trial started with a fixation cross (1s), a "ready?" prompt (until subject responded), and another fixation cross (1 sec); the last 2s of these events composed the "Preparation" period. Then the 3-word problem appeared (first 2s="Onset") and remained until subjects pressed a button to indicate solution (last 2s = "Solution"). ***B.*** Subjects blinked more frequently and longer prior to insight than analytic solutions, in both the Preparation and Solution periods. ***C***. Subjects made more fixations prior to analytic than insight solutions, in both the Preparation and Solution periods. ***D.*** Specific location of fixations in Solution period varied, subjects making more fixations on the problem words (inside the "box") prior to analytic solutions, and more fixations away from words prior to insight solutions.




* one tail t-test; ** two tails t-test.

## Discussion

The result demonstrates that insight is related to a tendency of avoiding visual information in two ways – the first by physically closing the eyes and the second by looking more to an area of the screen empty of visual distractors. Consistently with previous studies (Jung-Beeman et al., 2004; Kounios et al., 2006; Wood & Hassett, 1983) this result proves a distinct visual-attentive involvement in the two processes. The differences found corroborate the idea that solutions achieved via insight involve different cognitive mechanisms from those achieved via analysis. Different for previous findings, the technique of research allowed us to directly track the visual pattern on participant behavior.

Specifically, the data demonstrates that during the two seconds before the problem appears on the screen, solutions via insight are predicted by increased blink frequency and duration compared to solutions solved via analysis. The blink data is confirmed by both the decreasing of number of fixations – if people are blinking they are not fixating– and pupil size data. This result reveals that the strategy adopted to solve a problem is modulated by a specific preparatory behavior. As suggested by neural activity data (Kounios et al., 2006) the gating of external distracters primes the achieving of insight solutions.

The higher blinks rate suggests that in order to have an insight, attention needs to be driven internally, priming for the detection and retrieval of weakly-activated potential solutions played by ACC (Kounios et al., 2006). The connection between blinks and ACC is further corroborated by the role that the neurotransmitter dopamine (DA) plays as a mediator. Indeed, it has been shown to facilitate cognitive flexibility and improve creative problem solving as regulated by the ACC (Ashby, Isen, & Turken, 1999; Ashby, Valentin, & Turken, 2002), and marked by blinks (Chermahini & Hommel, 2010). More generally, it has also been demonstrated that higher levels of DA are connected with creativity (i.e., Ashby et al., 1999; Eysenck, 1993; Reuter, Roth, Holve, & Hennig, 2006) and less inhibition between alternative thoughts (Cohen & Servan-Schreiber, 1992).

Following the preparation, the onset period analysis shows no differences across the two solution styles. Our data reveals that in the first two seconds of the solution process participants approached the problem similarly, making frequent short fixations, probably because they were reading the words and starting to look for the solution.

The difference in the eye patterns turns out to be consistent with the alpha-band activity measured over the occipital cortex (Jung-Beeman et al., 2004) in the last two seconds of the solution period. When the insight is supposed to happen, participants blink longer and make less fixations. In Jung-Beeman's et al., (2004) study the alpha-band effect was recorded immediately before a burst of gamma-band activity located over the right anterior temporal lobe, starting about 0.3s before problem solved via insight. Because during the EEG experiment participants were instructed to keep their eyes open to minimize electrical noise from eye movements and blinks, the alpha effect was interpreted as a "brain's covert alternative to close the eye or looking away" that people would have spontaneously done as an ecological method to avoid distracters and focus more on the answer (Jung-Beeman et al., 2004; Kounios & Beeman, 2009). Here we were able to test this statement, letting participants move their eyes freely, resulting in an increase of blink duration before an insight solution. Even more interestingly, such an attempt to inhibit visual information turns out to be consistent also in the analysis of the different areas of the screen: on the problem words (or inside the “box”) and in the white space surrounding the problem (outside the “box”). Indeed, not only did participants blink longer when they solved problems with insight, but when they weren’t blinking they were gating inputs looking more (making and higher number of fixations and spending overall more time) in an area of the screen empty of visual distracters. This pattern replicates Reichle’s et al., (2010) result of participants averting their gaze from the text immediately before mind wondering and reminds us the behavior that everyone may easily observe in everyday circumstances, when people are asked a question and they avert their gaze.

The higher number of fixations located inside the “box” before a solution via analysis is explained as the final check out to see if the solution effectively fits the other three words.

We interpret this data as the terminal step of an analytical, deliberate, and sequential solution process, taking place above the threshold of awareness. This pattern also entails an intense visual inspection of the stimuli and is interpreted as a further evidence that the attention is oriented outward. Conversely an insight is unexpected, and two second before the solutions participants do not know the solution and they are probably just “feeling” (Metcalfe, 1986) close to the solution. Therefore to concentrate better they are more likely to switch their attention inwardly by gating visual information to better detect weakly-activated solutions.

To conclude, this study is a further physiological evidence of how the two solution methods diverge, triangulating the neurological model through EEG, FMRI and Eye Tracking to corroborate the idea that attention plays a pivotal role in leading to one process or the other.

[This research was done in collaboration with: Emanuela Bricolo, Steve Franconeri, John Kounios and Mark Beeman].

## Experiment 1.2

## –“*Eureka* hunting”

*“I close my eyes in order to see.”*

Paul Gauguin

**Introduction**

In the following study, Experiment 1.1’s findings are furthered by asking to people to close their eyes for three seconds before they saw the problem. The eye movement data demonstrated that insights are associated with a pattern oriented to avoid visual distractors, both blinking more and fixating into empty area of the screen. This suggests insight solutions are promoted by an inwardly attention allocation compare to solution via analysis, but it is not clear if the gating of inputs is triggered by a pure attentive top-down control or there might also be some bottom-up facilitators.

Eye blinks are not necessarily related to external inputs, indeed they have several different aims: reflexive, generated in response to environmental stimuli like a sudden fear; endogenous, reflecting allocation of attentional resources or also be made intentionally—in response to a command (Stern, Walrath, & Goldstein, 1984). Depending on the kind of blink, they may or may no be affected by visual stimuli, indeed a different pattern of response to blink has been emerged in absence of retinal stimulation (Bristow et al., 2005). By dissociating extra-retinal effects of blinking from its mechanical or optical effect, it had been demonstrated that blinking suppress activity in visual cortex and in areas of parietal and prefrontal cortex. Tsubota et al., (1999) found an activation of the visual cortex under condition of darkness that cannot be attributed to photoreceptor activities, and they suggested such activity to be due to an attention involvement.

The capability of filtering out distracting stimuli while completing selective attention tasks is negatively related to performance on open-ended tests of creativity such as sorting objects and decoding pattern meanings (Dykes & McGhie, 1976; Rawlings, 1985), completing unfinished drawings (Necka, 1999), and writing creative poems (Kasof, 1997). People who have more real-world creative achievements also reveal reduced ability to screen out irrelevant stimuli from current attentional focus (Carson, Peterson, & Higgins, 2003). More generally it has been shown how more distractible people tend to have an "Aha!" moment more often then step-by-step solutions on selective attention tasks (Ansburg & Hill, 2003; Mendelsohn & Griswold, 1964; Mendelsohn & Lindholm, 1972). The relation between attention (focus *vs* broad) and problem solving style has recently been demonstrated to be mutual. Wegbreit, Suzuki, Grabowecky, Kounios, and Beeman, (2012) have shown that inducing a state of broad attention is conducive to insight solving, and focus of attention appear conducive to analytic solving, whereas an employment of more focused attention states primed participants who later solved more Anagrams via analysis. Again, Kounios et al., (2008) found an association between individual differences in attention traits and solutions via insight or analysis. Resting-state EEG was recorded before the participants were tasked. A diffuse attentional state primed participants who later solved more Anagrams via insight. Several pieces of evidence endorse the involvement of attention in insight/noninsight problem solving by now, e.g. ACC and occipital cortex activation priming (Kounios et al., 2006). The blink data found in Experiment 1.1 further supplements the idea of attention to be implicated in solution style adoption.

Taken together it seems quite clear that attention modulates the employed solution method, and that this involvement corresponds to the same occipital cortex activity which affects blinking (Bristow, et al., 2005). It is not that clear if the insight brain activity might also be selectively affected by a lack of external visual inputs. In the current Experiment we wondered if the difference found in blinking and in the occipital cortex is just evidence of attention involvement which controls endogenous eye blinks, or if also a lack of visual inputs might modulate attention and then affect the solution strategy adopted. As O'Regan, Deubel, Clark, and Rensink's (2000) study demonstrated, blinks trigger a failure to detect changes probably due to a switch of attention towards different target of the visual field, so we predicted that closure of participants' eyes may redirect attention to promote insight solutions.

**Method**

*Participants*

Twenty-seven students at the University of Milano-Bicocca participated at the Experiment (21 females; age M 22.3; SD 1.9). All participants were right-handed.

*Stimuli and apparatus*

Subjects were presented with 100 line drawings (black on a white background) of objects at level 2, taken from the Snodgrass and Vanderwart (1980) normed set. Picture level of segmentation refers to Snodgrass and Corwin, (1988) where segments containing black pixels were randomly and cumulatively deleted to produce seven incrementally fragmented versions of each picture; level varied from 8 (complete picture) to 1 (most fragmented), the proportion of deleted segments for any level equals [1–0.7 (level-1)]. Insight “Aha!” experience has been observed in perception (Porter, 1954; Rubin, Nakayama, & Shapley, 1997; Rubin, Nakayama, & Shapley, 2002) as picture recognition has been demonstrated to be valid task to study this type of problem solving (e.g. recently Ludmer, Dudai, & Rubin, 2011). The stimuli were presented on a 19-in. Samsung SyncMaster 1200nf monitor with a 1024 x 768 pixel resolution. Experiment Builder software (SR Research) was used to program the experiment, stimulus presentation and for response recording.

*Procedure*

Participants were tested individually. Four practice trials and instructions about how to distinguish insight from analytic problem solving were given prior to the experiment. Each trial began with a response prompt screen. Once participants were ready the fragmented picture was presented on the screen. In half of the cases participants were asked, by a screen instruction, to close their eyes for 3 seconds before they saw the figure. When participants were closing their eyes a white screen was displayed, then the fragmented line drawing appeared. Picture order and condition were randomized every time. Following the production of a solution by pressing a button, or the end of the time limit (15s), the images were erased and subjects had to press the left or the right button of the mouse if solved they the problem via insight or via analysis (left/right buttons difference and insight/analysis type of solution correspondence was balanced between subjects). No feedback was given to the participants regarding whether the solution they provided was accurate or inaccurate. In total the experiment took approximately 40 minutes. Instructions used to describe insight or analysis were the same used in Experiment 1.1 traslated into Italian. Participants were instructed that no solving style was any better or any worse than the other and there were no right or wrong answers in reporting insight or analytic.

**Results**

Only problems solved correctly were considered in the analysis. Participants overall solved 46.8% (M 46.8; SD 9.75 on 100 given) of problems. Because problems solved faster than two seconds were considered immediate recognitions, and those solved in the last five seconds an attempt to guess, they were removed from the analysis[1]. The remaining problems were the 56.1% (M 26.2; SD 8.6) of those solved in the whole period of time, 58.1% (M 15.3; SD 6.8) of which via insight and 41.9% (M 11; SD 7.9) via analysis. The averages of response times were 3.3s, (SD 0.5) for solutions via insight; 5.2s, (SD 0.9) for solutions via analysis (two tails t-test, $t(26)= -7.03$; $p < .001$). Overall, the average of solution percentages was significantly higher for problems primed by eyes closure (M 53.7%; SD 0.1) compare to the baseline (M 46.3%; SD 0.1) (two tails t-test, $t(26)= - 2.36$; $p < .05$). In the baseline condition participants solved an average of 12.4 (SD 5.1) problems, no significant difference was found in the average of solution percentages, respectively 56.5% (SD 0.3) of problems were solved via insight and 43.5% (SD 0.3) via analysis. A significant difference (two tails t-test, $t(26) = 2.92$; $p < .01$) between insight and analysis solutions was found in the eyes closed priming condition (M13.9; SD 4.4), indeed an average of 62.2% (SD 0.2) of problems were solved via insight and 37.8% (SD 0.2) via

[1] The data about the whole solution period do not differ in significance from those of the time window selected (i.e. discarding the first two and the last five seconds).

analysis. No significant difference was found in comparing solutions via insight or analysis across the baseline and the closing eyes condition.

**Discussion**

As the result shows closing the eyes before people attempt to solve a problem improves the correct solution percentages overall. Within this condition a significant difference was found across problems solved via insight compared to those solved via analysis. Taken together these data show that closing the eyes in general improves problem solving, and this advantage is due to a higher percentage of solutions via insight. In the baseline condition no significant differences were found across the two solution methods, suggesting that in neutral condition neither insight nor analysis were encouraged. Moreover the percentages of solution averages are not significant across the baseline and the closed eye condition. This suggests that closing the eyes by itself promotes solutions via insight over those via analysis and thus significantly increases the percentage of solutions, but that closing the eyes does not trigger significantly more insights (an average of 62%) compared to a baseline condition where an average of 56% of solutions are via insight anyway. Overall the data endorses the initial hypothesis according to which bottom-up gating of inputs modulates insight solutions promoting it. In fact, more insight solutions were obtained when participants closed their eyes before they saw the problems. This result is consistent with eye movement pattern found in Experiment 1.1 and it also suggests that there is a mutual interaction between visual inputs and insight problem solving. This goes beyond a selective top-down attentive modulation; the data suggests that this system may also be guided by the physical lack of visual inputs.

In sum the experiment shows that in a baseline situation (therefore in the same scenario used in experiment 1.1), insight solutions are almost as frequent as solutions via analysis, they are associated with a higher number of blinks, and with blinks which are longer lasting (Exp 1.1). If the amount of visual information is experimentally reduced by making participants close their eyes, then the percentage problems solved by insight increases significantly compared to those solved by analysis.

Closing the eyes is clearly not the switch for lighting the light bulb above our heads, but the data is also clearly telling us that there is a way to facilitate the "electric current" there, and it is related with preventing visual information.

**Conclusion**

In Experiments 1 and 2 I further supplement the neurological model developed by Beeman, Bowden and Kounios (Bowden & Jung-Beeman, 2003b; Bowden et al., 2005; Kounios, et al., 2006; Kounios & Beeman, 2009; Subramaniam et al., Kounios, Parrish, & Jung-Beeman, 2009b). Consistently with the findings the model is based on, Experiments 1 and 2 demonstrated that:

- Insight problem solving entails an involvement of visual system oriented to inhibit inputs, by blinking more (in both number and duration) and fixating less or outside of the problem area;
- insight also benefits from an absence of visual inputs gained through closing the eyes.

These two findings are the next steps to further the idea of attention having a pivotal role in the insight solution process. The increased number of fixations and neural activity, measured by EEG over visual cortex, (Kounios, et al., 2006) indicates participants were preparing for analytical solving, by directing attention outwardly. On the contrary, preparation for solving an upcoming problem with insight presupposes directing attention inwardly — by blinking more and for longer time probably to prime the detection and retrieval of weakly activated potential solutions (Kounios, et al., 2006). The perspective of inward attention to endorse insight solutions is further supported by bottom-up evidence. Indeed the blocking of visual inputs by closing the eyes demonstrated to improve insight solution (Exp. 1.2). These two studies provide behavioral evidence for what was theorized by neurological activation of brain regions (Bowden et al., 2005; Jung-Beeman et al., 2004; Kounios & Beeman, 2009). Moreover, by showing that insight may be influenced by explicit inward attention allocation thanks to the absence of visual stimuli, these findings open doors for future studies of insight.

In Experiment 1.1, we provided an explanation of the alpha effect by the eye blink result. We showed that in free vision (when participants are not discourage to close their eyes), instead of decrease visual inputs by reducing occipital cortex activity, participants spontaneously blink more or fixate outside of the problem area. This explanation could be further supplemented by combining multiple techniques of research in the same experiment; e.g. eye tracking, fMRY and EEG.

I acknowledge that one limitation to the conclusions is that I combined the outcomes of different kind of problems in the same frame of explanation. These results still need to be replicated, preferably using the same either purely visual or linguistic material. This weak point has been due to the lack of an Italian version of the CRA restriction that motivated the study described in the last Chapter. This limitation may be addressed in other studies, for instance, if the experiment was to be replicated based on the "Visual Aha" material using the CRA and vice versa, or by again moving the closed-eye window from the preparation period to the solution period.

## 2. Aha is right! Insight solutions are more likely to be correct than are analytic solutions

*"All great achievements of science must start from intuitive knowledge.*
*I believe in intuition and inspiration...*
*At times I feel certain I am right while not knowing the reason."*

Albert Einstein

### Introduction

Popular imagery often depicts insight as a suddenly illuminated light bulb appearing above someone's head, or through the Archimedian exclamation: "*Eureka!*" Vitruvius's books of architecture report that the Greek mathematician had been tasked with solving the problem proposed by the Hiero II of Syracuse for assessing the purity of an irregular golden votive crown, and achieved the solution through a swift intuition. According to the story, Archimedes was taking a bath when the solution suddenly arose in his mind. Astonished, he jumped from the tub and ran through the streets screaming "*Eureka*!"

A posteriori scientific research has since come to define two problem-solving strategies, either of which Archimedes could have used. The first is a systematic process where the solution is achieved gradually and unsurprising, it needs testing, the intermediate steps are known and the strategy used is reportable (Ericsson & Simon, 1993; Metcalfe & Wiebe, 1987; Metcalfe, 1986; Newell & Simon, 1972). The second is a sudden emergence of the solution into awareness as a whole - which is characterized by an “Aha!” feeling. In this case the intermediate steps are unknown, the processes leading to solution are unreportable and the solution feels obvious (Metcalfe & Wiebe, 1987; Smith & Kounios, 1996). Almost certainly, Archimedes achieved the solution via the latter, now defined as insight (Bowden et al., 2005; Maier, 1931; Sternberg & Davidson, 1995). His sudden “*Eureka*!” exclamation behaviorally indexed a discrete information process, distinct from the continuous and more incremental process of the former (Kounios, Osman, & Meyer, 1987; Meyer, Irwin, Osman, & Kounios, 1988; Sergent & Dehaene, 2004). This episode suggests us that insight is also associated with an inherent confidence in solution’s accuracy, at least enough to run through the streets shouting “*Eureka*!”. We wander if Archimedes’ *Eureka* was just “lucky” or his public display of enthusiasm was actually supported by a higher likelihood of being correct.

To answer it we investigated whether the accuracy rate actually differs between insight and analytical problem solving strategies. Insight process starts with an initial in-depth detection, a weak activation of remote solution-related info that remains outside of awareness. Through convergence and integration, the solution emerges as a whole, tied to all problem elements, through a switch from unconscious to conscious processing it triggers the sudden “Aha!” feeling (Jung-Beeman et al., 2004; Kounios & Beeman, 2009). This integration of the problem concepts is non-obvious for the individual, and therefore contextually non-biased. (Bowden et al., 2005). A central role in detecting weakly activated solutions and to switch attention to them has been attribute to the increased activity of the ACC during the rest period (ibid., page 16). This area of the brain has been shown to be involved in detection of competing responses, shifting attention to alternatives ideas, detecting errors and suppressing irrelevant thoughts (ibid., page 17). Reversely, solutions via analysis start with an external attentional orientation indexed by the increased activity over the visual cortex (Kounios et al., 2006; Ibid., Exp 1). The path to achieve the solution is fragmented into multiple steps, in each of which the solver is focused on, but also under the risk of errors. This study investigates if this multiple steps process is also more likely to incur in errors compared to an all-at-once insight solution. Indeed, if in each step of the solution process the solver might run in to an error, then the number of errors should be higher in a multiple step process.

During the analytical process, people attempt to consciously connect the problem given to the most related information available, until a solution is achieved. It works differently for insight where the information useful to achieve the solution remains weakly activated under the level of consciousness, and only if the integration of it fits with the solution than it becomes aware. Therefore, the accuracy might be the key-feature that catches the attention on the potential solution candidate, which suddenly pops up in to the solver consciousness also triggering the "Aha!" feeling. As a consequence insight is an on-off process that is more likely to be correct.

In 1986 Metcalfe, by tracking the warmth rating trend during the solution process, found that when an insight occurs, a problem's warmth rating did not increase until immediately before the solution, while the pattern showed an incremental trend when insight was not involved. In addition, she showed that problems solved by an insight pattern were more likely to be correct compared to those solved incrementally. Metcalfe speculated that the higher rate of errors made using the analytical strategy was from participants relying on the use of a "*successive approximations strategy*." In other words, they convinced themselves to accept a good-enough answer, a phenomena she found to occur more frequently when subjects were encouraged to guess. Beside this, the accuracy result seems to predict the same pattern that the neural model suggested. In the same direction, other research concluded that problem solutions achieved via analysis were yielded through an incremental and partial response completion of information, whereas those achieved via insight were through an all-or-none process (Smith & Kounios, 1996). This pattern predicts that subjects using an analytical strategy access partial information about the correct response before the solution is attained, and therefore they would be more likely to guess as they approach the solution (Kounios, Fleck, Green, Payne, Stevenson, Bowden, & Jung-Beeman, 2008). Consistently, Kounios et al., (2008) data shown that those who are more likely to use insight strategy make more errors of omission (i.e. timeouts), whereas people that use the analytical strategy more often make errors of commission (i.e. incorrect responses).

These studies pioneered the idea of accuracy differences between insight and analytical solutions. Nevertheless results still needed further empirical investigation because accuracy by itself has never been specifically detected and existing data were mere byproducts of related studies. Moreover, there is no consistency across different types of problems to allow a considerable demonstration of the phenomena. This study represents the first attempt to specifically focus on how different problem solving styles lead up to the production of correct or incorrect solutions using four different types of problems: one pure linguistic (like the CRA by Bowden and Jung-Beeman, 2003a) one pure visual (degraded lines drawing of Snodgrass and Vanderwart, 1980) and two both linguistic and visual (Rebus Puzzles by MacGregor and Cunningham, 2008, and Anagrams). In order to better isolate unbiased responses, exclude any response differences between the two solution methods, and to compare the result with Metcalfe's, we excluded answers given in the first two seconds (when participants were likely to have immediately recognized the solution) and those provided in the latest five seconds of the solution time (when participants might be more prompt to guess or to convince themselves to be stress about running out of time). This made it possible to cohere real analytical and insight solutions from answers which participants may have improperly named insight just because they immediately solved them, or analytic because they were guessing. In any case results regarding the whole solution time are reported in Appendix 2.

## Experiment 2.1 – CRA

### Method

*Participants*

Twenty-one undergraduate students (age M 18.5; SD 0.6; 11females) from Northwestern University (Evanston, IL) participated in the experiment for partial course credit. All participants were right-handed and native speakers of American English.

*Stimuli and apparatus*

The stimuli used we the same CRA world problems used in Exp. 1.1 (Ibid., page 24).

*Procedure*

The same procedure described in Exp. 1.1 was used (Ibid., pages 24, 25). No feedback was given to the participants regarding whether the solution they provided was accurate or inaccurate. In total the experiment took approximately one hour. Solving a CRA problem via insight was described as, "the answer suddenly came to your mind and you were unable to explicitly state how the solution was obtained, (i.e., an "Aha!" moment)." Solving the CRA problem analytically was described as, "you can explicitly state how the solution was obtained." Participants were instructed that no solving style was any better or any worse than the other and there were no right or wrong answers in reporting insight or analytic. Participants were asked to do their best on each problem. Furthermore they were told that the problems ranged in level of difficulty and they would therefore be unable to solve every problem.

**Results**

Participants overall answered (correctly or incorrectly) to 44.9% (M 53.2) of problems given. Only 77.5% (M 51.2) of those were considered in the analysis (because problems solved before two seconds and in the last five seconds were excluded). Out of all answers labeled as insight (62.5%; M 25.8), an average of 94.8% (SD 6.4; M 24.2) were correct while out of all those labeled as analysis (36.5%; M 15.5), an average of 85.5% (SD 14.1; M 13.6) were correct. Significantly more problems solved with insight were correct compared to those solved via analysis (Two tails t-test; $t(20) = 2.61$; $p < .05$). A repeated measures 2 x 2 ANOVA comparing solution times of problem solving styles (i.e., insight *vs* analytic) and solution accuracy (i.e., correct *vs* error) showed a main effect of solution style ($F(1,15) = 42.07$; $p < .001$) and significant interaction effect ($F(1,15) = 5.65$; $p < .05$). The averages of response times were: correct-insight 4.63s, (SD 0.7); correct-analysis 6.72s, (SD 1.1); incorrect-insight 5.76s (SD 1.5); incorrect analysis 7.17s (SD 1.2).

## Experiment 2.2 – Anagrams

**Method**

*Participants*

Fifty-one undergraduate students participated in the experiment. All participants were right-handed and native speakers of American English.

*Stimuli*

The stimuli were 180 Anagrams (109 four-letter and 71 five-letter Anagrams), preceded by a practice block of 14 Anagrams. The Anagrams were generated using a computer program described by Vincent, Goldberg, & Titone (2006). Each anagram had only one solution. The mean bigram sum of the solutions was 5954.91 (S.D. 2555.31). The mean word frequency (Francis & Kucera, 1982) for the solutions was 54.75 per million (S.D. 93.79). Anagrams can be solved with a moment of insight or analytically. Self-reports differentiating between insight and analytic solving have demonstrated reliability in previous studies (i.e. Bowden, 1997; Dougal & Schooler, 2007; Kounios, Fleck, Green, Payne, Stevenson, Bowden, & Jung-Beeman, 2008).

*Procedure*

Each trial started with a 0.5s fixation plus-sign followed by an anagram which was displayed at the center of screen (replacing the plus sign) until the subject either responded with a computer-mouse button-press or the trial timed out (at 16s after the onset of the anagram). Anagrams' order was randomized every time. Subjects were instructed to press a button with their right index finger immediately upon deriving the solution (thereby terminating display of the anagram), and 0.5s later they viewed a message which prompted them to verbalize the solution. After each solution (correct and incorrect), subjects were asked to press a button to indicate whether the solution was derived with insight, without insight, or 'not sure.' Insight was explained to subjects as occurring when the solution pops into awareness suddenly (i.e., an "Aha!" moment), as opposed to resulting from deliberate and conscious rearrangement of the letters of the anagram. The time expired after 16 seconds. Subjects were instructed with a 14 practice trials at the beginning of the experiment. In total the experiment took approximately one hour. The data reported was collected by Kounios et al., in 2004 and 2012 at Drexel University, Philadelphia, PA. The accuracy result was subsequentially analyzed by me for this study.

**Results**

Participants overall answered (correctly and incorrectly) to 72.1% (M 130) of problems given, 68.7% (M 89.2) of which used for the analysis. An average of 56.1% (M 49.3) of trials were labeled as insight while 43.9% (M 39.9) analysis. Significantly more problems solved with insight (M 97.6%; SD 5; M 48) were correct compared to those solved via analysis (M 91.8%; SD 15.1; M 37.4) (Two tails t-test; $t(50) = 2.64$; $p < .05$).

A repeated measures 2 x 2 ANOVA comparing solution times of problem solving styles (i.e., insight versus analytic) and solution accuracy (i.e., correct versus error) showed a main effect of solution style ($F(1,37) = 17.56$; $p < .001$) and significant interaction effect ($F(1,37) = 20.69$; $p < .001$). The averages of response times were: correct-insight 4.88s, (SD 0.9); correct-analysis 5.10s, (SD 1.3); incorrect-insight 6.59s (SD 2.5); incorrect analysis 6.87s (SD 1.9).

## Experiment 2.3 – Visual Aha

**Method**

*Participants*

Twenty-seven students at the University of Milano-Bicocca participated at the Experiment (age M 22.3; SD 1.9; 21 females) for partial course credits. All participants were right-handed.

*Stimuli and apparatus*

Subjects were presented with 50 line drawings (black on a white background) of objects at level 2, taken from the Snodgrass and Vanderwart (1980) normed set. Picture level of segmentation refers to Snodgrass and Corwin (1988) where segments containing black pixels were randomly and cumulatively deleted to produce seven incrementally fragmented versions of each picture; level varied from 8 (complete picture) to 1 (most fragmented), the proportion of deleted segments for any level equals [1–0.7 (level-1)]. Insight “Aha!” experience has been observed in perception (Porter, 1954; Rubin et al., 1997; Rubin et al., 2002), as picture recognition has been demonstrated to be valid task to study this type of problem solving (e.g. recently Ludmer, Dudai, & Rubin, 2011).

*Procedure*

Each trial began with a response prompt screen. Once participants were ready the fragmented picture was presented on the screen. Pictures' order was randomized every time. Following the production of a solution by pressing a button, or the end of the time limit (15s), the images were erased than subjects had to press the left or the right button of the mouse if they solved the problem via insight or via analysis (left/right buttons difference and insight/analysis type of solution correspondence was balanced between subjects). No feedback was given to the participants regarding whether the solution they provided was accurate or inaccurate. In total the experiment took approximately 20 minutes. Instructions used to describe insight or analysis were the same used in Exp.2.1 traslated in Italian. Participants were instructed that no solving style was any better or any worse than the other and there were no right or wrong answers in reporting insight or analytic. Three practice trials and instructions about how to distinguish insight from analytic problem solving were given prior to the experiment.

**Results**

71.3% (M 35.7) of problems given were answered, 60.4% (M 21.6) of which used for the analysis, respectively an average of 46.3% (SD 22.4; M 10) of solutions were via insight and M 53.7 % (SD 22.4; M 11.6) were via analysis. Significantly more problems solved with insight (M 66%; SD 25.5; M 6.9) were correct compared to those solved via analysis (M 45.3%; SD 25.5; M 5.48) (Two tails t-test; $t(26) = 2.97$; $p < .01$). A repeated measures 2 x 2 ANOVA comparing solution times of problem solving styles (i.e., insight versus analytic) and solution accuracy (i.e., correct versus error) showed a main effect of solution style ($F(1,23) = 65.13$; $p < .001$) and accuracy ($F(1,23) = 7.11$; $p < .05$). The averages of response times were: correct-insight 3.25s, (SD 0.6); correct-analysis 5.17s, (SD 1.4); incorrect-insight 4.10s (SD 1.5); incorrect analysis 5.69s (SD 1.2).

## Experiment 2.4 – Rebus Puzzle

### Method

*Participants*

One-hundred and ten undergraduate students (age M 21.2; SD 4.8; 81 females) from the University of Milano-Bicocca participated in the experiment for partial course credit. All participants were right-handed and native Italian speakers

*Stimuli and apparatus*

Rebus Puzzles (RP) have been demonstrated to be a valid source of insight problems (MacGregor & Cunningham, 2008). Similarly to MacGregor and Cunningham we combined verbal and visual clues to a common phrase, such as T+U+T+T+O ("tutto sommato" – all summate, is a common Italian phase which could be translated as "all considerate") in order to create a set of Italian Rebus Puzzles. First we selected one-hundred nine common phases that could be used as the solution of the Rebus Puzzles. Twenty-nine undergraduate students at University of Milano-Bicocca (age M 23.6; SD 2.9; 11 females) assessed the familiarity with each phrase. Only phrases with a score above 3 on a scale from 1 (less familiar) to 5 (more familiar) were selected to create Rebus Puzzles. Ninety nine RPs remained from the initial pool, these were examined separately by two different judges who selected the encrypting devices involved to countermanded the normal assumptions of reading. Nineteen categories were identified, for instance: trend (growing, decreasing, etc., as in LUNA "luna calante" – (decreasing / waning moon); counting (e.g., Cycle, Cycle, Cycle "tricycle"); and interpreting colors as words (e.g., **ESSERE** "essere al verde" – to be "at" the green is a common Italian phase which means to have no money – see item 71, Appendix 5, page 90). Based on this categorization the RPs were split into 3 different blocks (31 each). In order to avoid any effect of solution influence we maintained similar problems separated.

*Procedure*

Each trial began with a response prompt screen. Once participants were ready they had to press the keyboard space button for the each RP to be presented individually on the screen. Following the production of a solution, or the end of time limit (15s), the RP was erased and subjects had to typewrite the solution and decide how they solved the problem: via insight or via analysis. After answering to the solution method used, participants also had to specify if the solution given were influenced by any other problems presented before. No feedback was given to the participants regarding whether the solution they provided was accurate or inaccurate. Four practice RPs and instructions (the same of Exp. 2.3) regarding how to distinguish insight from analysis problem solving were given prior to the experiment. Each participant attempted to solve only one block (32 RPs) of the three selected. In total the experiment took approximately 20 minutes.

**Results**

RPs which obtained 0% and 100% of solution rate (11 RPs total) and those with a writing response latency more than the average +1SD of each RP (9.5% on total) were discarded from the analysis. The remained problems (both correct and incorrect) were 65.4% (M 20.7), 61.2% (M 12.65) of which used for the analysis. An average of 59.5% (SD 25.6; M 7.5) of answers were via insight and 40.5% (SD 25.6; M 5.1) via analysis. Across all the insight answers, significantly more were correct (M 75.1%; SD 25.8; M 5.7) compared to analytical ones (M 58%; SD 34.8; M 3.4) (Two-tails t-test; t(109)= 4.19; $p < .0001$). A repeated measures 2 x 2 ANOVA comparing solution times of problem solving styles (i.e., insight versus analytic) and solution accuracy (i.e., correct versus error) showed a main effect of solution style ($F(1,70) = 35.79$; $p < .001$), accuracy ($F(1,70) = 6.16$; $p < .05$) and interaction as well ($F(1,70) = 9.46$; $p < .005$). The averages of response times were: correct-insight 3.97s, (SD 1.1); correct-analysis 4.88s, (SD 1.6); incorrect-insight 5.13s (SD 1.7); incorrect analysis 5.89s (SD 1.8).

Individually each type of problem shows that solutions via insight are more likely to be associated with correct answers compare to solutions via analysis. The consistency of the result across the four problems is proved by the non significant interaction between insight *vs* analysis correct solution (2 X 2 ANOVA ($F(3,205)=20.23$; $p = .174$).

**Discussion**

Participants reported generating their correct solutions more often with insight than with analysis and their incorrect solutions more often with analysis than with insight in four different tasks and types of stimuli. This data demonstrates that answers achieved via insight are more likely to be correct than answers produced via analysis, consistently across quite a heterogeneous class of problems. All the problems which could not be considered pure solutions via insight or via analysis were excluded (i.e. those solved less than two and in the last 5 seconds). This time windows selection, by reducing the marginal tails of the time distribution, prevents any supplementary cause (or extra-explanations) due to time difference. As it is shown in Appendix 2, it actually reduces the effect which would have been more robust if the whole time of solution would have been used. Time differences across solution styles are further discussed at page 66.

**Guessing result and discussion**

Metcalfe's (1986) data showed that when participants are encouraged to guess, the incremental pattern is more likely to be associated with errors compared to the insight one. Instead of boosting participants to guess we considered the last five seconds as a temporal window where participants are more likely to guess because they are running out of time. Therefore, these problems were excluded from previous analysis because considered not pure problem-solving answers.

The percentages of problems solved in the last 5 seconds compared to all the answers given in the whole period were: 18.6 % (M 9.9) for the CRA; 9.5 % (M 12.3) for Anagrams; 7.3% (M 2.6) for Visual Aha and 8.2% (M 1.7) for the Rebus Puzzles. The average of percentages across insight/analysis answers given were: insight 29.7% (SD 17.3;

M 3.1), analysis 70.3% (SD 17.3; M 6.8) of CRAs; insight 57.3% (SD 32.5; M 7.4), analysis 42.7% (SD 32.5; M 5) of Anagrams; insight 17.3% (SD 33.5; M 0.4), analysis 75.2% (SD 39.6; M 2.2) of Visual Ahas; insight 34.6% (SD 40.4; M 0.7), analysis 47.3% (SD 43.2; M 1) of Rebus Puzzles.

| | +2/-5sec | | | -5/end sec | | | + 2 /-5 sec *vs* -5/end sec | |
|---|---|---|---|---|---|---|---|---|
| Problem | M % | SD | M problems | M % | SD | M problems | Two tails t-test | |
| CRA | 8.6 | 0.06 | 3.5 | 25.1 | 0.27 | 2.8 | p < .001 | |
| Anagrams | 4.4 | 0.05 | 3.8 | 11.4 | 0.14 | 1.4 | p < .005 | |
| Visual Aha | 42.2 | 0.19 | 9.2 | 67.2 | 0.34 | 1.9 | p < .005 | |
| Rebus Puzzle | 28.1 | 0.2 | 3.6 | 47.8 | 0.4 | 1 | p < .001 | |
| | | | | | | | p < .001 | Tot |

| | Insight errors | | | Analysis errors | | | Insight/Analysis errors | + 2 /-5 sec *vs* -5/end sec Two tails t-test | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Problem | M % | SD | M problems | M % | SD | M problems | Two tails t-test | Insight | Analysis | |
| CRA | 10.3 | 20.1 | 0.4 | 29.4 | 32.4 | 2.4 | p < .005 | – | p < .001 | |
| Anagrams | 4.6 | 10.9 | 0.4 | 20.2 | 31.4 | 1 | p < .005 | – | p < .05 | |
| Visual Aha | 16 | 36.2 | 0.2 | 62.7 | 37 | 1.5 | p < .005 | – | – | |
| Rebus Puzzle | 20.5 | 38.3 | 0.3 | 38.9 | 45.6 | 0.7 | p < .005 | – | – | |
| | | | | | | | | – | p < .001 | Tot |

**Table 1**
The table above compares the average of percentages, and numbers of errors, made in the time window used for all of the analyses (discarding the first two and the last five seconds) and last five seconds. As the last column shows, significantly more errors are made in the last five seconds compared to the rest of the solution time. The result is consistent across all the kinds of problems examined. In the table below only errors made in the last five seconds are considered, both via insight and via analysis. In the last five second more errors with analysis were made in all the problems considered. In the last two columns are compared the errors made in the solution period (discarding the first two and the last five seconds) with the errors made in the last five seconds. Overall only errors made via analysis were significantly higher in the last five seconds, specifically those made with the CRA and the anagram tasks.

The data shows that, independently of the strategy used, answers given in the last five seconds are more likely to be incorrect, this result is consistent across all type of problems analyzed. Only for the analytical strategy the percentage of problems solved incorrectly in the last five seconds was overall significantly higher compared to the rest of the solution time. The consistency of this analysis with Metcalfe's, corroborates the assumption that problems solved in the last five seconds are mostly an attempt to guess. More interestingly, our result was significant only for linguistic problems (CRAs and Anagrams) not for those visual (Visual Ahas and Rebus Puzzles). Whereas, for insight solutions, there are no significant differences of incorrect responses when time is expiring or not, overall and across the different type of problems. This data is read as due to the unconscious and discrete nature of insight. Different from analysis, during insight there is no access to the processing information before the solution is attained, so people have no candidates to use as a guess when time is expiring.

**Conclusion**

This study examines how problem-solving style interacts with solution accuracy using four problems, each of which involves different cognitive skills and processes: linguistic, visuospatial or some combination of both. The result robustly demonstrates that insight solutions are more likely to be correct when compared to solutions via analysis. This study is the first attempt to specifically focus on the accuracy components of insight. Furthermore, it integrates Metcalfe's (1986) and Kounios's et al., (2008) results, corroborating the demonstration of insight answers to be more accurate then those obtained via analysis and it opens a dialogue about the cognitive mechanisms responsible for such a different result.

The increased accuracy of insight solutions is interpreted as due to the integration of non-biased multiple weak associations from all problem elements to the solutions, which summate to boost the activation of the solution concept into consciousness. The consequent result is that when the solution does emerge, it necessarily fits with the problem elements given. To support this explanation there is the perspective that considers creativity as derived from the processing of remote associations between ideas (Mednick, 1962) and the more recent studies which shown a central role played by the right hemisphere in insight problem solving (Bowden & Beeman, 1998; Schooler, Fallshore, & Fiore, 1995). This side of the brain is engaged in the integration of weak remote information, is therefore more likely to maintain diffuse activation of alternative meanings, distant associations and solution-relevant concepts (Bowden & Jung-Beeman, 2003b; Bowden et al., 2005). This initial in-deep analysis of the potential candidate takes place before the problem is presented to the participants. The ACC activation before insight solutions may reflect a readiness to: monitor for competition among potential responses, help to suppress the wrong answers, and enable to the correct candidate to be isolated from the irrelevant information to shift attention to a nonprepotent solution if it is detected (Kounios, 2006).

Thus far, is had been outlined that the analytical path is more likely to be associated with incorrect responses as a higher rate of errors of commission (Kounios et al., 2008); probably due to a *successive approximations strategy* that convinces the solver to accept a "good-enough" answer (Metcalfe, 1986). This may explain the higher percentage of incorrect solutions given in the last five seconds, but it does not explain why participants do not claim to solve a problem with insight in the last five seconds of solution time –when they running out of time therefore guessing. Why can an insight not be an attempt to guess? Insight is an all-or-none mechanism, mainly processed below the threshold of consciousness and only retroactively identifiable; therefore subjects using this strategy do not have access to information about the answer before the insight happens (Smith & Kounios, 1996). Ergo, if insight has not occurred when the solution time is expiring, participants do not have any answer to guess with. Indeed they are more likely to commit errors of omission (Kounios et al., 2008). Reversely, noninsight solutions are more incremental, consciously step-by-step processed, therefore participants have access to the information they are manipulating and they are more aware to the partial correctness of their solution during the process. By the time the deadline is approaching, participants are probably more prone to guess giving the response that has been elaborate so far. This explanation is supported by Kounios et al., (2008) which also shows that insight solvers make more errors of omission, while noninsight solvers make more errors of commission. Alternatively, we might consider the difference found during the last five seconds of solution also a stress condition caused by running out of time. An increase in activity of the noradrenergic system occurs during stressful situations (Kvetnasky, Pacak, Sabban, Kopin, & Goldstein, 1998; Ward et al., 1983) and it reduces flexibility of access to semantic/associative networks during the task (Martindale & Greenough, 1973). Stress has been demonstrated to impair creativity and cognitive flexibility (e.g. Alexander, Hillier, Smith, Tivarus, & Beversdorf, 2007; Beversdorf, Hughes, Steinberg, Lewis, & Heilman, 1999), it is modulated by task difficulty (Campbell, Tivarus, Hillier, & Beversdorf, 2008) and it affects performance accuracy (Beilock & Decaro, 2007). In this case the result might be due to the increased pressure felt in the last five seconds of solution, especially for problems not solved at the beginning so perceived more difficult by participants. Both of these explanations support the idea of insight to be more susceptible to an internal interference which first activates the right answer, eventually letting it pop up at the level of consciousness.

This outcome might also be explained according to probability. A solution via analysis is achieved trough a fragmented path of “n” number of steps, in each of which the solver can make an error, than take the wrong direction of reasoning and miss the right solution. This means that more steps the reasoning implies more the final answer is likely to be wrong. Thereby, a one-step path like insight is still error-sensitive but less compared to a multi-step procedure. Indeed, also insight answers were found to be wrong, but the percentage was lower compared to those via analysis. It is difficult to detect how many steps a solution has taken without having participants’ verbal protocols with which to calculate a proportion between steps and percentage of solution. The only number this study accesses is the overall solution percentage, and that makes us to assume a difference in the number of steps across the solution methods as a possible explanation. In a multi-step process the probability of a correct answer is conditioned by having also correctly accomplished all the previous steps. Following this, the correct answer is achieved only if step1, step2, step3… step “n” are correct. Assuming the steps have the same level of difficulty, a one-step process like insight might also associated with errors, but because it implies only one step (so the answer can be right or wrong) the probability of making an error is not conditional to any previous steps. For example, let’s take a one step solution path (S1) and compare the probability to make an error with a simple two steps solution path (S2):

S1) Given one step solution path: the result can be either A (correct) or $\bar{A}$ (non correct), the probability of $\bar{A}$ is 1 minus the probability of A:

$$P(\bar{A}) = 1-P(A)$$

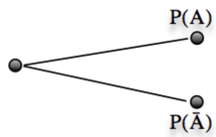



**Figure 2** shows the two ways the one-step process of reasoning may take: right or wrong. No other steps probability influences the result.

S2) Given a two steps solution path: Sa (step a) and Sb (step b) with P(A) > 0, the conditional probability of B given A is defined as the quotient of the joint probability of B and A, and the

probability of A:

$$P\ (B|A) = \frac{P(B \cap A)}{P(A)}$$

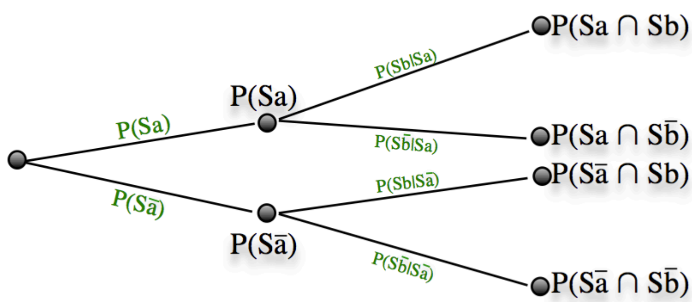



**Figure 3**
Two steps solution process tree diagram. In each branch probabilities are conditional on the event with the parent node.

As a result, the probability of making an error increases conditionally to the correctness of the steps required to arrive at the solution. One way to test this explanation in future studies might be to check through verbal protocols, predicting a correlation between errors and steps made during the solution process.

The outcome might also be interpreted as to be due to a higher working memory load, which has shown to be associated with errors when problem solving involves intermediate solutions or nested goals (Seyler, Kirk, & Ashcraft, 2003). This interpretation brings with itself the eventuality to consider a parallel *vs* serial processes difference, where insight is parallel and analysis serial.

The current study does not prove one strategy more successful than the other, especially considering the higher rate of errors of omission found by Kounios et al., (2008), but it demonstrates that when we have an insight, the solution we achieve is more likely to be right compared to a solution via analysis. While explanations for the results are not conclusive in regards to the initial question of what cognitive mechanism causes the difference in accuracy found, they still raise several arguments that might be further elaborated in the future research. For instance, this study may have us conclude that Archimedes' insight, and his ecstatic behavior, was justified empirically by the increased likelihood that insight solutions are correct. But may we say that this is also related with the self-confidence Archimedes displayed?

[This research was done in collaboration with: Emanuela Bricolo, Edward Bowden, Kounios and Mark Beeman].

## General discussion

After nearly one century since the Gestaltists introduced the concept of insight, the scientific community has significantly progressed in understanding it. Insight problem solving has peculiar characteristics that differentiate it from noninsight ones. For instance, people are incapable of predicting that they would solve a problem via insight whereas they are able to predict fairly well a noninsight approach to the solution (Metcalfe & Wiebe, 1987; Metcalfe, 1986). Most scholars agree that analytic solving involves methodical, strategic, step-by-step processing, where each (successful) step diminish the distance to the goal. Although solving may take time, the necessary steps are generally known or deducible, and people gradually approach solution (Metcalfe & Wiebe, 1987). Instead, for insight, the path necessary to solve is unsettled at the beginning of the problem, until the solution arises suddenly and feels obvious, but even after solution, solvers are incapable to report the processes that conducted to it (Schooler, Ohlsson, & Brooks, 1993). As the Gestalt school initially outlined insight problem solving has been demonstrate to be a distinct type of problem-solving, which involves at least some precise cognitive mechanisms, and a unique brain activity. Indeed, a robust number of experiments have demonstrated that participants' subjective judgments of solution type correlate with objective measures of behavior and of brain activity (Jung-Beeman et al., 2004). For instance, participants show different patterns of semantic priming during insight and noninsight solutions (Bowden & Jung-Beeman, 2003b). Thanks to the neuroscientific approach, insight has been discovered to be a right hemisphere process related to a distinct neural correlates compared to solutions with analysis (Jung-Beeman et al., 2004; Kounios et al., 2006; Subramaniam et al., 2009). Specifically, the process that leads to the “Aha!” moment starts even before participants approach the problem. Indeed during the preparation period of problems eventually solved via insight, our brain activates a cognitive pattern oriented to avoid visual distractors (by making more frequent and longer lasting blinks; Exp. 1.1). This is finalized to drive attention inwardly, priming for the detection and retrieval of weakly-activated potential solutions played by ACC. Conversely noninsight solutions are primed by an increased neural activity over the visual cortex and by making more fixations (Exp.1), which index an outward allocation of attention (Kounios et al., 2006; Kounios at al., 2008).

Taken together these results suggested that the strategy adopted to solve a problem is modulated by a specific preparatory attentional behavior which opens up the possibility to facilitate one strategy of solution or another. Indeed, as it as been demonstrated an induced state of focus or unfocused attention triggers a solution via analysis or via insight (Kounios et al., 2008; Wegbreit et al., 2012; Exp. 1.2). In the first chapter we have shown that insight benefits from an absence of visual inputs gained through closing the eyes, and that is associated with an eye movement pattern oriented to avoid visual distractors, increasing blink rates and looking outside the “box” containing problem information. These findings raise further ideas about the possibility to facilitate a *Eureka* moment, maybe by modulating the attention direction when people are stuck in an impasse or by asking them to close their eyes.

Diffuse attention advances the recruitment of remote associations because it improves recognition of peripheral environmental stimuli that could serve as cues that trigger retrieval of such associations (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). The idea that diffused attention could be involved in insight is further corroborated by the fact that during the preparation period ACC activation is accompanied by resting state brain activity (Kounios et al., 2006; Kounios et al., 2008). This finding implies that top-down cognitive control mechanisms promote the maintenance or switching of intentional focus and a selection from competing responses (which we investigated in Chapter 2 of this essay).

Insight process starts with an initial in-deep analysis of the potential solution, demonstrated by the ACC activation, which has the role of monitoring for competition between candidates, helping to suppress the wrong answers, and enabling to the right answer to be isolated from the noise, in order to shift attention on it if it is detected (Kounios, 2006). This inward analysis, which is more likely to be successful, is promoted by gating visual inputs. Indeed, as Glenberg et al., (1998) have shown people are more accurate when they avert their gaze (or close their eyes) than when they do not. In Chapter 2 we deeply investigated the accuracy side of the phenomena, comparing the results of four different problems. The result demonstrates that solutions given via insight are more likely to be right compare to those via analysis, clarifying the role played by ACC and implementing the model adopted. Besides the explanation based on the neurological evidence this data pioneers further considerations, so possible speculations of the cognitive processes involved that need to be detected.

*Time Concerns*

Although we tried to reduce time differences in the two solution methods, for instance by excluding the first two and the last five seconds of problem solving in Chapter 2, time difference is still evidence that characterizes insight and noninsight answers. Nevertheless, this variable might tell us something more about the two processes that should be considered.

One of the features that may explain time difference is that that an analytical process needs testing. Indeed as Exp. 1.1 proves, in the last two seconds of the problems solved via analysis participants' number of fixations increases significantly. This means that before giving a response obtained via analysis participants double check whether the potential solution fits with the information provided on the screen. This implies more time. Insight answers, instead, are prompt and given right after the participant has the "Aha!" moment. It might also have to deal with confidence implications, i.e. insight solutions feels more right than those via analysis (and the actually are) so participants do not make any further testing.

Time and accuracy difference also suggest a serial *vs* parallel classification of the two processes. In a serial system, each item is processed sequentially, so a new item is considered only when the previous one is completed. As a result, the overall amount of time is a sum of the time taken by each item when processed. Conversely, several items or subsystems are processed simultaneously in a parallel system, although processing may finish on different results at different times. In either type of operation, both serial and parallel times may be random. However, in the first one each successive subtask taking the same average duration is of limited capacity with respect to the overall total processing time required for an increasing number of subtasks. Therefore, more tasks there are to do more the overall time for all the subtasks increases (Townsend, 1990). We found that insight and analytical processes differ in time and accuracy and in the same way, most of the known criteria to classify serial *vs* parallel processes are based on reaction times and accuracy, with the strongest method for classification combining the two. As this conclusion is just a speculation derived from the results, further studies need to prove it. For instance, (as Townsend, 1990, suggests) to classify insight as a parallel process it would be necessary demonstrate that the reaction time decrease despite an increasing of processed items.

To allow this and more other studies to be done in the future, we developed and tested an Italian version of two sets of problems, which are described below.

## **Appendix 1** – Validation of the Italian CRA and Rebus Puzzle tests

### Introduction

In the Italian scientific landscape there is a lack of studies about insight problem solving, likely due to an absence of efficient tests to use. Indeed, only few of the more recent class of insight problems are usable in other languages than English (e.g. The Matchstick Arithmetic of Knoblich, Ohlsson, Haider, and Rhenius, –1999; and the fragmented pictures from – normed set). In order to encourage the research of this vein of problem solving, we proposed the Italian version of two types of problems which have been precluded since now (i.e. Compound Remote Associates by Bowden and Jung-Beeman, – 2003a, and Rebus Puzzles by MacGregor and Cunningham, – 2008).

*How to study insight in Italy?*

As discussed in the introduction, CRAs represent a pivotal contribution of the new approach for studying insight problem solving as they enabled a great deal of new research. The CRAs with the RPs present several advantages over classic insight problems. First and foremost being that they provide a substantial amount of problems from which to choose which are easy to explain, have multiple levels of difficulty, and which do not require a domain-specific knowledge to solve.

We have developed the Italian version of these two sets of problems patterned after items in the CRA and the RP in order to allow the study of insight problem solving in Italy as well, and benefit from their advantages. The main aim of this study is to create and validate a robust pool of problems providing normative information regarding solution times and the relative difficulty of each problem that may be selected as stimuli for future studies.

Both of these tests have been demonstrated to be solvable both with insight and noninsight strategies (Bowden & Beeman, 1998; MacGregor & Cunningham, 2008). Different from pure analytical problems (e.g. the Towers of Hanoi) they share properties attributed to insight problems like: Solvers come across an impasse because it is misdirected by ambiguous information in the problem (Dominowski & Dallob, 1995; Smith, 1995). Solvers are not able to describe the processing adopted to overcome the impasse (Gick & Lockhart, 1996; Ohlsson, 1992). A sudden "Aha!" experience accompanies the solution of the problem (Metcalfe & Wiebe, 1987; Janet Metcalfe, 1986; Sternberg & Davidson, 1995).

As already introduced (ibid., page 10), researchers using classic insight problems have faced two obstacles. Classic insight problems were usually few and too difficult to solve, so that participants were not able to attempt enough of them in an experimental session reducing the reliability of the data recorded. The two selected problems instead: 1) Can be solved in a short time (such as 15s). 2) They are easier than classic insight problems, thus many of them may be correctly solved in the same session. 3) They involve linguistic and visuospatial skills to be solved. 4) They can be easily presented in a small visual space, like the one usually available in neuroscience studies. Taken together, these features improve the control on the experiment and record of measurement variables.

**Italian CRA 3.1**

The CRA by Bowden and Jung-Beeman, (2003a) was inspired by a simpler version named Remote Associates Test (RAT), developed by Mednick (1962). The RAT was created to study creativity neutrally without expecting any specific knowledge, it consists in two sets of 30 items (Mednick & Mednick, 1967; Mednick, 1968). Each item is composed of three words that can be associated with a fourth word by creating a compound word, by semantic association or because they are synonyms. Success in solving RAT has been demonstrated to correlate with success in solving classic insight problems (Dallob & Dominowski, 1993; Schooler & Melcher, 1995). In the CRA, Bowden and Jung-Beeman (2003a) supplemented the RAT version increasing the number of problems and they limited the association between the triad and the solution to a formation of a compound word (or phrase) (e.g., *crab, pine, sauce* form the compounds *crab- apple, pineapple* and *apple-sauce* with the solution word *apple*). Both the two tests have been consistency used in the study of problem solving, cognitive flexibility and creative thinking (e.g., Ansburg, 2003; Ansburg & Hill, 2003; Ansburg, 2000; Beeman & Bowden, 2000; Bowden & Beeman, 1998; Bowden & Jung-Beeman, 2003b; Campbell et al., 2008; Dallob & Dominowski, 1993; Jung-Beeman et al., 2004; Schooler & Melcher, 1995; Subramaniam et al., 2009a). They have been used in a homogeneity of studies including attention (Rowe, Hirsh, & Anderson, 2007; Wegbreit et al., 2012), psychopathology (e.g., Fodor, 1999), motivation in sexual selection (Griskevicius, Cialdini, & Kenrick, 2006) and affect (e.g., Mikulincer & Sheffi, 2000).

The RAT has already been successfully translated Japanese, Jamaican and Hebrew (Baba, 1982; Hamilton, 1982; Nevo & Levin, 1978) to allow the study of creativity and insight problem solving in other languages as well. Our study is the first and only attempt to create an Italian version of the CRA.

**Italian Rebus Puzzle 3.2**

What makes the RPs an interesting pool of problems to study insight is the common principle where relationships (e.g. like the space between the letters in a word, their color, font size or style) of problem components have to be verbally interpreted in order to achieve the solution. In other words, the solver has to "restructure" the formal interpretation of reading, by relaxing their ingrained constraints, in order to shift in how problem elements are cognitively or perceptually represented (MacGregor & Cunningham, 2008). Indeed, as MacGregor and Cunningham (2008) demonstrated, the difficulty of each rebus is related to the number of principles used to encrypt a phrase or saying, thus it depends on the number of implicit assumptions that would have to be relaxed to solve a rebus. Ergo, solving rebuses may require relaxing one or more of the constraints necessaries in processing standard text, features considered an important component of insight problem solving (Ohlsson, 1992).

For example, in "**FRATELLO**" ("grande fratello" i.e. "big brother"), the visual attribute of the font has to be interpreted verbally, which is not done in usual reading. The rebus "CIE LO" (apriti cielo; i.e. "open sky"), is solved by decoding the relative positions of components spatially, rather than grammatically as in normal reading.

**Method**

*Stimuli and apparatus*

CRA

A set of 150 CRA problems (three Italian words each) was initially created. For all problems there was a fourth solution word that could be associated with all three words of the triad through formation of a compound word or phrase (e.g., *danno, lavoro* and *giro* form the compounds *capodanno, capolavoro*, and *capogiro* with the solution word *capo*). Problem words were sometimes repeated (e.g., *libero* is repeated four times) but solution words were never repeated or used as problem words.

REBUS PUZZLES

A pool of Italian Rebus Puzzles were patterned after rebus in MacGregor and Cunningham (2008) Rebus Puzzles by combining verbal and visual clues to a common phrase, such as T+U+T+T+O ("*tutto sommato*" – all summate, is a common Italian phase which could be translated as "all considered"). Twenty-nine undergraduate students at University of Milano-Bicocca (age M 23.6; SD 2.9; 11 females) assessed the familiarity of 109 common phases, that could be used as the solution of the Rebus Puzzles. Only phrases with a score above 3 on a scale from 1 (less familiar) to 5 (more familiar) were selected to create Rebus Puzzles. Ninety nine RPs remained and these were examined separately by two judges who analyzed the encrypting devices involved to countermanded the normal assumptions of reading. Nineteen categories were identified, for instance: trend (growing, decreasing, etc., as in LUNA "luna calante" – decreasing moon); counting (e.g., Cycle, Cycle, Cycle "tricycle"); and interpreting colors as words (e.g., "*essere al verde*" – to be "at" green is a common Italian phase which means to have no money – see item 71, Appendix 5, page 90).

*Pre-tests*

This initial pool 150 CRAs was first divided in three blocks (50 problems each) and based on the categorization described the 99 RPs were split in 3 different blocks (31 each). A total of 50 CRAs and 31 RPs were given to 110 undergraduate students (age M 21.2; SD 4.8; 81females) from the University of Milano-Bicocca for partial course credits. Each participant received only one block of CRAs (35 students were assigned to block A, 35 to block B and 40 to block C) and one block of RPs. The order of blocks presentation (CRA-RP or RP-CRA) was randomized. This pre-test allowed us to better refine the final valid pool of 122 CRAs and 88 RPs, discarding too easy problems (i.e. 100% of solution), too difficult (i.e. 0% of solution) and those which two possible valid solutions were found. The items and the normative data for the solvability of these items is in the Appendixes 3, 4 and 5.

**Final test**

*Participants*

An initial sample of 297 participants (M age = 25.88; SD=8.75, min=16, max=65; 227 females) was recruited. Participants that declared not to be Italian native speakers, or that did not complete the experiments seriously were discarded. The final sample consisted in 269 subjects (M age=25.76; SD=8.56; min=16, max=65; 205 females), 78% of them were students recruited from the University of Milano-Bicocca and the rest from the web.

*Procedure*

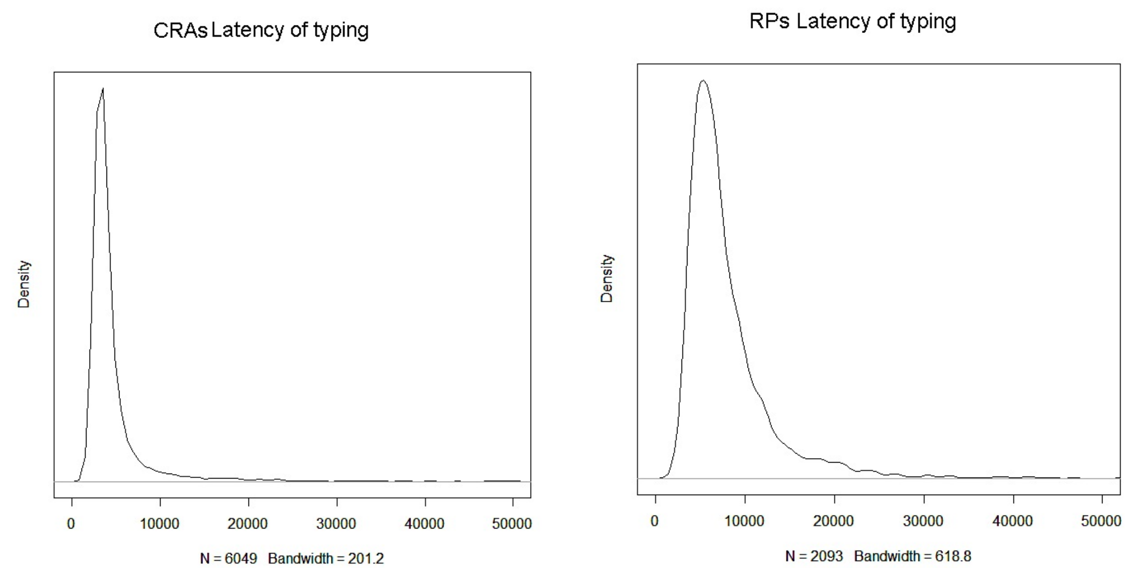
The 122 CRAs were splitted in 3 blocks (41-41 and 40 items each), and the 88 RP in 9 balanced for category blocks (9 to 11 items each)[2]. Participants attempted to solve only one block of each kind of problems. The order of presentation and pairing of blocks were randomized. The experiment was run on-line trough INQUISIT Millisecond software package (Inquisit beta 4.0.0.1, 2012). The same software was used to program, present and record responces. INQUISIT measures response times with millisecond accuracy (De Clercq, Crombez, Buysse, & Roeyers, 2003). Three and four practice trials preceeded the CRA and the RP sessions respectively. Each trial began with a response prompt screen. Once participants were ready they had to press the keyboard space button for the each CRA or RP to be presented individually on the screen. Following the production of a solution, the item was erased and subjects had to typewrite the solution and decide how they solved the problem: via insight or via analysis. When participants ran out of time, the next problem was immediately displayed. No feedback was given regarding whether the solution was accurate or inaccurate. Instructions (the same of Exp 2.3 and 2.4) regarding how to distinguish insight from analysis problem solving were given prior to the experiment. (i.e. *Per INSIGHT si intende che la risposta ti è venuta improvvisamente in mente, senza essere in grado di spiegare come l'hai trovata. Questo tipo di soluzione si associa spesso ad esclamazioni di sorpresa come "Aha!". ANALITICAMENTE invece significa che hai individuato la risposta dopo aver deliberatamente e consapevolmente provato diverse parole fino a quando non hai trovato quella corretta. In questo caso ad esempio saresti in grado di indicare i passaggi che ti hanno portato alla soluzione".* Moreover, it was specifically asked to participants to perform the test alone, to isolate themselves from any

[2] In order to separate the RP of the same category the number of RP for each block varies from 9 to 11 items.

source of distraction or noise. They were instructed that no solving style was any better or any worse than the other and there were no right or wrong answers in reporting insight or analytic. Participants were asked to take the test seriously do their best on each problem. The availability of the answers given was double checked at the end of the test through a set of questions (i.e. participants were asked if they solved the problems alone or not, if they had already solved those problems before and if they preformed seriously or not). Only subjects that completed this final questionnaire were included, those that dropped the experiment before were excluded from the analyses. In total the experiment took approximately 25 minutes.

**Results**

We calculated the percentage of participants solving each problem within each of the time limits. In order to guarantee the 15 seconds time limit to be respected, answers typed in more than 10 seconds for the CRAs and 15 seconds for RPs were discarded. These cut offs have been calculated to be sufficient for typing the answers by the distribution of them.




**Figures 4 and 5** Distribution of answers given in the CRA and RP problems across a time typing line.

The data of both tests is presented in the Appendix 3 and 4 in descending order according to the percentage of participants producing a solution within the 15-seconds time limit.

By providing solvability and time-to-solution data, we hope to benefit the use of Remote Associate Problems and Rebus Puzzles to study insight problem solving in Italy as well.

[This research was done in collaboration with: Giulio Costantini, Emanuela Bricolo, and Marco Perugini].

## Appendix 2

The analysis of experiments 2.1, 2.2, 2.3 and 2.4 below considers the whole solution time period.

| | Insight correct solutions | | | Analysis correct solutions | | | |
|---|---|---|---|---|---|---|---|
| Problem | M % | SD | M problems | M % | SD | M problems | Sig. |
| CRA | 94.4 | 6.3 | 28.5 | 79.9 | 17 | 18.3 | p < .001 |
| Anagrams | 97.6 | 5.3 | 72.4 | 91.9 | 13.6 | 51.9 | p < .01 |
| Visual Aha | 79.2 | 15.3 | 16.5 | 43.1 | 23.7 | 6.8 | p < .001 |
| Rebus Puzzle | 78.5 | 19.8 | 10.4 | 58 | 32.4 | 5.3 | p < .001 |

**Table 2**
In table 2 the averages of percentage and number of problems are compared, correctly solved via insight and via analysis. The data refers to the whole solution period across the four different types of problems analyzed. In all of the problems analyzed, significantly more insight solutions were correct compared to those solved by analysis.

## Appendix 3

| | | | | % of | | | | |
|---|---|---|---|---|---|---|---|---|
| CRA Items | Solutions | Mean Solution Time (sec) | SD | Participants Solving Item | Errors | Timeouts | Answers Typed in More than 10 sec | No Answers |
| CASELLA PRIORITARIA ELETTRONICA | posta | 3.30 | 1.57 | 98 | 0 | 1 | 1 | 0 |
| BIANCA CREDITO IDENTITA` | carta | 4.28 | 2.41 | 87 | 2 | 8 | 2 | 0 |
| ESPRESSO REGIONALE CAPO | treno | 4.86 | 2.39 | 87 | 4 | 8 | 2 | 0 |
| ERBA SPINATO DIRETTO | filo | 4.03 | 2.17 | 86 | 8 | 4 | 2 | 0 |
| GIUDIZIO MAL CANINO | dente | 5.65 | 2.83 | 86 | 1 | 12 | 2 | 0 |
| CAPRA SVIZZERO BUCHI | formaggio | 4.41 | 2.05 | 84 | 0 | 11 | 5 | 0 |
| GAS ZUCCHERO BAMBU' | canna | 6.42 | 3.13 | 83 | 2 | 11 | 4 | 0 |
| BERLINO PIANTO PORTANTE | muro | 4.46 | 2.26 | 83 | 5 | 11 | 1 | 0 |
| DIVANO SINGOLO FIUME | letto | 5.54 | 2.82 | 82 | 4 | 12 | 3 | 0 |
| PEPE MINIERA GROSSO | sale | 5.13 | 2.91 | 80 | 2 | 14 | 2 | 1 |
| AFRODITE BOTTICELLI STRABISMO | venere | 5.88 | 3.11 | 78 | 6 | 14 | 2 | 0 |
| PERDERE APPARENTE PIATTA | calma | 5.19 | 2.41 | 75 | 7 | 16 | 1 | 0 |
| COLPA SESTO LATO | senso | 5.63 | 2.84 | 69 | 1 | 28 | 1 | 0 |
| FRATELLO DITTATORE PUFFO | grande | 5.99 | 2.61 | 69 | 4 | 21 | 5 | 1 |
| TAPPETO POMODORO PESCE | rosso | 6.57 | 3.83 | 68 | 9 | 21 | 2 | 0 |
| MARINAIO SCARPA CRAVATTA | nodo | 6.99 | 2.97 | 65 | 7 | 24 | 4 | 0 |
| PARCO SALA CARTE | gioco | 6.29 | 3.06 | 64 | 5 | 21 | 10 | 0 |
| RIUNIONI BALLO ASPETTO | sala | 4.77 | 2.65 | 64 | 6 | 27 | 2 | 0 |
| VIAGGIO INVITO LISTA | nozze | 5.67 | 2.64 | 63 | 17 | 18 | 2 | 0 |
| LEGALE ESATTA PUNTA | ora | 3.84 | 2.64 | 59 | 6 | 33 | 1 | 0 |
| SANGUE TURCO PUBBLICO | blu | 6.25 | 3.64 | 59 | 6 | 34 | 2 | 0 |
| TAGLIARE MALTESE CIRCUITO | corto | 5.37 | 2.98 | 59 | 9 | 29 | 4 | 0 |
| ASTRALE ELETTRICO SVEDESE | quadro | 4.67 | 3.04 | 58 | 17 | 21 | 4 | 0 |
| CATTIVA IRONIA ESTRAZIONE | sorte | 5.28 | 2.59 | 58 | 4 | 31 | 7 | 0 |
| PAGLIA MEZZOGIORNO VIGILE | fuoco | 6.72 | 3.06 | 58 | 10 | 30 | 2 | 0 |
| CIGLIO MAESTRA BATTUTA | strada | 6.35 | 3.68 | 54 | 10 | 35 | 0 | 2 |
| PICCHE PUNTI RUOTE | due | 5.79 | 3.14 | 52 | 10 | 30 | 8 | 0 |
| CASSETTA ADESIVO AZZURRO | nastro | 6.86 | 3.37 | 52 | 10 | 35 | 4 | 0 |
| LEGNA GAS PATATE | forno | 5.83 | 2.58 | 51 | 17 | 29 | 3 | 0 |
| POVERA REGOLA CONTEMPORANEA | arte | 6.22 | 2.79 | 51 | 14 | 33 | 2 | 0 |
| NERO COLLETTO CONIGLIO | bianco | 7.08 | 2.89 | 50 | 10 | 36 | 5 | 0 |
| LINGUAGGIO STRADA CIVILE | codice | 5.56 | 3.13 | 49 | 12 | 31 | 7 | 0 |
| NOME ABITO SOTTO | sopra | 6.62 | 2.74 | 48 | 11 | 39 | 1 | 1 |
| TESORO PASQUA PEDONALE | isola | 5.98 | 3.18 | 48 | 6 | 40 | 6 | 0 |
| LUCE COMPLEANNO MOTORE | candela | 6.08 | 3.09 | 47 | 8 | 40 | 5 | 0 |
| PETROLIO SCIENZA DESIDERI | pozzo | 5.05 | 2.70 | 47 | 9 | 41 | 2 | 1 |
| SCI BALLO ATTERRAGGIO | pista | 4.19 | 2.44 | 47 | 20 | 28 | 5 | 0 |
| PENTOLE MUSICA CARICA | batteria | 7.05 | 2.82 | 47 | 10 | 40 | 4 | 0 |
| GIUDA FRANCESE DAMA | bacio | 5.58 | 3.21 | 46 | 13 | 38 | 2 | 0 |
| MAGGIORE MONTAGNA ARTIFICIALE | lago | 6.54 | 3.07 | 46 | 11 | 37 | 6 | 0 |
| AFFARI PULITA LIBERA | piazza | 5.14 | 2.91 | 44 | 26 | 25 | 5 | 0 |
| RAGAZZO PADRONE FAMIGLIA | padre | 7.38 | 2.93 | 43 | 13 | 40 | 3 | 0 |
| FALSO MONTAGNA DANZA | passo | 5.87 | 3.20 | 43 | 4 | 50 | 1 | 2 |
| SCOMMESSE ANGOLO MERCATO | calcio | 6.42 | 2.91 | 43 | 19 | 36 | 2 | 0 |
| VIA VECCHIO BATTUTO | ferro | 6.59 | 3.31 | 41 | 10 | 46 | 3 | 0 |
| CARTA REGALO BOMBA | pacco | 5.38 | 2.76 | 41 | 12 | 41 | 5 | 1 |
| ELETTRICA MONETA MARINA | corrente | 7.47 | 3.35 | 41 | 9 | 48 | 2 | 0 |

## **Appendix 3** (continued)

| CRA Items | Solutions | Mean Solution Time (sec) | SD | % of Participants Solving Item | % of Errors | % of Timeouts | % of Answers Typed in More than 10 sec | % of No Answers |
|---|---|---|---|---|---|---|---|---|
| *IMPERFETTO LIBERO REALE* | *tempo* | 5.50 | 3.15 | 40 | 20 | 37 | 2 | 0 |
| *SCOPO MEDAGLIA POMO* | *oro* | 8.89 | 2.89 | 40 | 9 | 38 | 12 | 1 |
| *BATTERE SCARPA SPILLO* | *tacco* | 7.10 | 3.24 | 40 | 25 | 30 | 6 | 0 |
| *NERO BUE COLPO* | *occhio* | 5.79 | 3.18 | 38 | 13 | 44 | 4 | 0 |
| *VENTI DESERTO MAGLIA* | *rosa* | 6.35 | 2.64 | 38 | 3 | 55 | 4 | 0 |
| *CAPITALE MORTE SOFFERENZA* | *pena* | 5.99 | 2.52 | 37 | 19 | 36 | 9 | 0 |
| *SANGUE CIELO OCCHIO* | *bagno* | 6.84 | 3.43 | 37 | 26 | 31 | 6 | 0 |
| *TRATTENERE TROMBA COLLO* | *fiato* | 7.47 | 3.51 | 37 | 10 | 51 | 2 | 0 |
| *BELLA INCOLLA CARBONE* | *copia* | 5.82 | 2.70 | 36 | 19 | 43 | 2 | 0 |
| *MAPPA ANGOLO GIRO* | *mondo* | 7.98 | 2.99 | 36 | 10 | 47 | 7 | 0 |
| *PRESA BIRRA ROSA* | *spina* | 6.32 | 2.44 | 36 | 20 | 42 | 2 | 0 |
| *LONDRA OCCHI ARROSTO* | *fumo* | 6.70 | 3.47 | 36 | 5 | 57 | 2 | 0 |
| *DO DOPPIO POLLO* | *petto* | 6.15 | 3.78 | 36 | 2 | 60 | 3 | 0 |
| *FREDDO LUNGO PAUSA* | *caffe`* | 7.13 | 2.92 | 36 | 22 | 38 | 4 | 0 |
| *PIEDE BOTTIGLIA BAR* | *collo* | 6.20 | 2.56 | 36 | 8 | 49 | 7 | 1 |
| *INDIA SECCO PIANTA* | *fico* | 4.89 | 2.85 | 35 | 9 | 53 | 4 | 0 |
| *SINTESI RITOCCO GRAFIA* | *foto* | 6.81 | 3.28 | 35 | 14 | 49 | 2 | 0 |
| *FORMATO CAPO CRISTIANA* | *famiglia* | 6.68 | 3.52 | 35 | 13 | 49 | 4 | 0 |
| *FORTUNA LIBERA SCORTA* | *ruota* | 4.64 | 3.03 | 34 | 13 | 49 | 4 | 0 |
| *FORTUNA TRASPORTO COMUNICAZIONE* | *mezzo* | 6.14 | 2.49 | 33 | 23 | 37 | 6 | 0 |
| *GONNA GOLF ERA* | *mini* | 7.10 | 3.74 | 33 | 5 | 57 | 5 | 0 |
| *SOLE CATTIVA ANNO* | *luce* | 7.07 | 3.35 | 33 | 7 | 56 | 2 | 1 |
| *OSSA CREPA OCA* | *pelle* | 6.31 | 3.54 | 32 | 10 | 56 | 2 | 0 |
| *MOBILE MUSICALE EMERGENZA* | *scala* | 5.79 | 3.37 | 31 | 24 | 43 | 2 | 0 |
| *MUSICALE PROVA IPOTETICO* | *periodo* | 7.21 | 3.28 | 31 | 24 | 42 | 4 | 0 |
| *AGO PESO COSTELLAZIONE* | *bilancia* | 5.54 | 3.50 | 31 | 10 | 54 | 5 | 1 |
| *GAS NOTIZIE CENTRI* | *fuga* | 5.26 | 3.05 | 30 | 10 | 57 | 4 | 0 |
| *PSICHE PRIMO PROPRIO* | *amore* | 7.04 | 4.20 | 30 | 13 | 52 | 5 | 0 |
| *FORTE BAR TERRA* | *piano* | 6.91 | 3.62 | 27 | 10 | 57 | 6 | 0 |
| *VIOLINO CASA PAROLA* | *chiave* | 6.35 | 3.44 | 27 | 11 | 58 | 4 | 0 |
| *INDICE CON PIEDE* | *dito* | 8.07 | 3.70 | 27 | 14 | 52 | 7 | 0 |
| *LINGUA LINEA PERLA* | *madre* | 5.92 | 3.11 | 26 | 20 | 50 | 4 | 0 |
| *SPARO LATTE STELLE* | *polvere* | 6.47 | 3.85 | 26 | 8 | 60 | 6 | 0 |
| *MADRE VIDEO TELEFONICA* | *sheda* | 4.65 | 2.49 | 26 | 37 | 33 | 5 | 0 |
| *SCUOLA TUTTO DOMANI* | *dopo* | 6.70 | 3.65 | 25 | 13 | 58 | 4 | 0 |
| *SCRITTO OPERA BUCATO* | *mano* | 9.14 | 3.25 | 25 | 17 | 57 | 1 | 0 |
| *CUORI VITTORIA CIELI* | *regina* | 7.35 | 3.43 | 24 | 16 | 54 | 5 | 1 |
| *CAPO SPERANZA LINEA* | *verde* | 9.29 | 4.16 | 24 | 26 | 42 | 8 | 0 |
| *MONDIALE NOLEGGIO RETTILINEO* | *moto* | 8.38 | 3.56 | 24 | 17 | 55 | 5 | 0 |
| *MORTO FORMA TOGLIERE* | *peso* | 9.04 | 3.35 | 23 | 22 | 49 | 5 | 0 |
| *NUZIALE POTERE DEBOLE* | *anello* | 5.60 | 2.84 | 22 | 48 | 23 | 6 | 0 |
| *ULTIMO ZERO LUCE* | *anno* | 6.75 | 3.20 | 22 | 19 | 56 | 3 | 0 |
| *CENERE FOGLIO PACCHI* | *porta* | 6.75 | 4.20 | 21 | 31 | 43 | 4 | 1 |
| *CONTROLLO SCACCHI AVORIO* | *torre* | 7.04 | 3.75 | 21 | 22 | 50 | 6 | 1 |
| *IO ALCOLICO UOMO* | *super* | 6.64 | 3.56 | 21 | 12 | 65 | 2 | 0 |
| *ARRESTO PARTENZA PASSO* | *falso* | 7.24 | 2.64 | 21 | 27 | 47 | 4 | 1 |
| *CASSA LUOGO SENSO* | *comune* | 4.96 | 2.12 | 20 | 14 | 63 | 2 | 0 |

## **Appendix 3** (continued)

| CRA Items | Solutions | Mean Solution Time (sec) | SD | % of Participants Solving Item | Errors | Timeouts | Answers Typed in More than 10 sec | No Answers |
|---|---|---|---|---|---|---|---|---|
| *LOCALE SANA MALATO* | *mente* | 8.39 | 3.68 | 20 | 11 | 63 | 6 | 0 |
| *GOVERNO GENTILUOMO APPARTAMENTO* | *ladro* | 6.52 | 3.52 | 20 | 18 | 61 | 1 | 0 |
| *PUBBLICO FUORI COMUNE* | *luogo* | 6.51 | 2.41 | 20 | 21 | 57 | 2 | 0 |
| *RUOTE VINCITORE GRANDE* | *carro* | 7.58 | 3.16 | 19 | 8 | 71 | 2 | 0 |
| *BUCO TESSUTO DURO* | *osso* | 8.81 | 3.30 | 19 | 6 | 69 | 5 | 1 |
| *POSIZIONE ALLENTARE GIRO* | *presa* | 8.61 | 3.32 | 19 | 33 | 44 | 4 | 0 |
| *FESTA PRIMA CANNONE* | *donna* | 9.63 | 3.31 | 19 | 5 | 74 | 2 | 0 |
| *CONTINUA CLASSE LIBERA* | *lotta* | 4.74 | 2.66 | 17 | 21 | 61 | 1 | 0 |
| *MECCANICO FERRO MORTE* | *braccio* | 7.36 | 4.04 | 17 | 10 | 67 | 7 | 0 |
| *MANO QUOTIDIANO AFFARE* | *fatto* | 8.97 | 3.41 | 15 | 17 | 62 | 6 | 0 |
| *MUTA TEATRO REATO* | *scena* | 6.79 | 2.75 | 13 | 13 | 70 | 4 | 0 |
| *CLASSE STRADA LEGGE* | *diario* | 4.39 | 3.56 | 13 | 31 | 50 | 7 | 0 |
| *CLASSE VIAGGIO BORDO* | *fuori* | 6.81 | 3.84 | 13 | 20 | 60 | 7 | 1 |
| *BAGNO SCENA INTERO* | *costume* | 6.48 | 3.27 | 12 | 7 | 75 | 5 | 0 |
| *ROSSA INDIANO RADIO* | *freccia* | 9.17 | 3.25 | 12 | 19 | 64 | 5 | 0 |
| *CIELI LEONE SOLE* | *re* | 8.48 | 3.80 | 12 | 17 | 68 | 3 | 0 |
| *BASSA BRONZO NORD* | *lega* | 7.24 | 2.51 | 11 | 11 | 74 | 4 | 0 |
| *CANE CARO MINA* | *vita* | 9.07 | 3.11 | 11 | 14 | 73 | 2 | 0 |
| *PIEDE CENTRO NEVE* | *palla* | 4.67 | 2.36 | 10 | 10 | 77 | 4 | 0 |
| *ACQUA NERO ORECCHIO* | *buco* | 9.45 | 3.31 | 9 | 7 | 80 | 4 | 0 |
| *DANNO GIRO LAVORO* | *capo* | 7.75 | 2.61 | 9 | 21 | 69 | 1 | 0 |
| *COSCIENZA BLOCCO AUTO* | *posto* | 10.15 | 2.93 | 8 | 24 | 62 | 7 | 0 |
| *SEGUIRE CINESE GOVERNO* | *ombra* | 7.79 | 3.36 | 6 | 15 | 74 | 5 | 0 |
| *BLU PAVONE AMICO* | *penna* | 6.60 | 4.64 | 6 | 4 | 88 | 2 | 1 |
| *SUB GENERALE CATTOLICA* | *cultura* | 12.36 | 1.68 | 4 | 27 | 63 | 5 | 1 |
| *FORZA NOTTE NERA* | *camicia* | 8.16 | 3.17 | 4 | 15 | 76 | 4 | 1 |
| *LOGO CONTRO TESI* | *pro* | 8.30 | 2.14 | 2 | 16 | 78 | 4 | 0 |
| *DATA ONORE MANGIARE* | *parola* | 0.00 | 0.00 | 0 | 10 | 87 | 4 | 0 |

All the CRAs tested are reported in **Appendix 3.** Also in the table are the mean solution times for responses, with the respective standard deviation, the percentages of participants solving each item, errors, timeouts, answers typed in more than 10 s and items which did not receive any answers. The CRAs are sorted from the higher percentage of solution to the lowest.

# Appendix 4

| RP Items | Solutions | Mean Solution Time (sec) | SD | % of Participants Solving Item | Errors | Timeouts | Answers Typed in More than 15 sec | No Answers |
|---|---|---|---|---|---|---|---|---|
| 1 | *due di picche* | 2.47 | 1.34 | 100 | 0 | 0 | 0 | 0 |
| 2 | *tagliare la corda* | 1.63 | 0.58 | 100 | 0 | 0 | 0 | 0 |
| 3 | *avere la testa tra le nuvole* | 1.74 | 0.72 | 100 | 0 | 0 | 0 | 0 |
| 4 | *meno male* | 1.90 | 1.25 | 100 | 0 | 0 | 0 | 0 |
| 5 | *maglione* | 3.62 | 2.20 | 97 | 0 | 3 | 0 | 0 |
| 6 | *acqua in bocca* | 2.17 | 1.05 | 94 | 0 | 0 | 6 | 0 |
| 7 | *pan di stelle* | 1.93 | 0.96 | 94 | 6 | 0 | 0 | 0 |
| 8 | *chiave inglese* | 2.24 | 1.54 | 94 | 3 | 0 | 3 | 0 |
| 9 | *cantar vittoria* | 2.37 | 1.40 | 94 | 0 | 6 | 0 | 0 |
| 10 | *piove sul bagnato* | 3.27 | 2.78 | 93 | 0 | 3 | 3 | 0 |
| 11 | *avere il sangue blu* | 3.18 | 2.90 | 91 | 4 | 4 | 0 | 0 |
| 12 | *tra il dire e il fare c'e` di mezzo il mare* | 2.34 | 1.72 | 91 | 0 | 0 | 9 | 0 |
| 13 | *latte alle ginocchia* | 3.31 | 2.12 | 88 | 0 | 8 | 4 | 0 |
| 14 | *avere le braccine corte* | 3.48 | 2.90 | 86 | 3 | 6 | 6 | 0 |
| 15 | *mettere radici* | 1.98 | 0.98 | 85 | 15 | 0 | 0 | 0 |
| 16 | *non avere peli sulla lingua* | 2.85 | 1.32 | 82 | 6 | 0 | 12 | 0 |
| 17 | *dormire sugli allori* | 2.50 | 1.11 | 81 | 15 | 0 | 4 | 0 |
| 18 | *attimo fuggente* | 2.71 | 1.81 | 80 | 11 | 6 | 3 | 0 |
| 19 | *asso nella manica* | 4.89 | 3.38 | 79 | 3 | 10 | 7 | 0 |
| 20 | *ne` carne ne` pesce* | 2.78 | 3.14 | 79 | 6 | 3 | 12 | 0 |
| 21 | *una rondine non fa primavera* | 2.86 | 1.63 | 77 | 3 | 9 | 11 | 0 |
| 22 | *a maggior ragione* | 4.04 | 2.87 | 77 | 19 | 0 | 4 | 0 |
| 23 | *bruciare le tappe* | 3.34 | 2.50 | 77 | 12 | 8 | 4 | 0 |
| 24 | *orche-stra* | 3.76 | 1.40 | 77 | 15 | 8 | 0 | 0 |
| 25 | *pan di spagna* | 2.59 | 1.14 | 77 | 7 | 10 | 7 | 0 |
| 26 | *sotto a chi tocca* | 3.23 | 2.47 | 75 | 3 | 22 | 0 | 0 |
| 27 | *fare le ore piccole* | 3.16 | 2.14 | 74 | 9 | 13 | 4 | 0 |
| 28 | *fare il passo piu` lungo della gamba* | 2.75 | 1.83 | 73 | 4 | 12 | 12 | 0 |
| 29 | *tavola rotonda* | 2.48 | 1.71 | 73 | 23 | 0 | 4 | 0 |
| 30 | *essere di manica larga* | 2.91 | 3.06 | 73 | 12 | 8 | 8 | 0 |
| 31 | *mettere la mano sul fuoco* | 3.54 | 1.98 | 73 | 6 | 6 | 15 | 0 |
| 32 | *darci dentro* | 2.43 | 1.33 | 71 | 6 | 20 | 3 | 0 |
| 33 | *avere le mani bucate* | 3.07 | 2.18 | 71 | 21 | 6 | 3 | 0 |
| 34 | *contare le pecore* | 3.23 | 1.67 | 70 | 17 | 9 | 4 | 0 |
| 35 | *mettere i puntini sulle i* | 3.19 | 1.73 | 67 | 6 | 21 | 6 | 0 |
| 36 | *mettere/avere la pulce nell'orecchio* | 5.38 | 3.38 | 66 | 0 | 16 | 19 | 0 |
| 37 | *terzo incomodo* | 3.07 | 2.89 | 65 | 23 | 8 | 4 | 0 |
| 38 | *pane al pane vino al vino* | 2.46 | 0.82 | 65 | 13 | 17 | 4 | 0 |
| 39 | *calcio d'angolo* | 4.32 | 2.84 | 65 | 17 | 13 | 4 | 0 |

## **Appendix 4** (continued)

| RP Items | Solutions | Mean Solution Time (sec) | SD | % of Participants Solving Item | Errors | Timeouts | Answers Typed in More than 15 sec | No Answers |
|---|---|---|---|---|---|---|---|---|
| 40 | *il tempo vola* | 2.29 | 1.05 | 65 | 26 | 4 | 4 | 0 |
| 41 | *prendere fischi per fiaschi* | 4.55 | 2.82 | 65 | 3 | 21 | 12 | 0 |
| 42 | *passa parola* | 3.33 | 2.76 | 63 | 20 | 10 | 7 | 0 |
| 43 | *andare a nozze* | 2.73 | 1.99 | 62 | 21 | 17 | 0 | 0 |
| 44 | *triciclo* | 3.41 | 2.54 | 62 | 31 | 8 | 0 | 0 |
| 45 | *farne di tutti i colori* | 2.69 | 1.25 | 59 | 13 | 25 | 3 | 0 |
| 46 | *avere le mani nel sacco* | 3.12 | 1.88 | 59 | 15 | 6 | 21 | 0 |
| 47 | *cercare un ago nel pagliaio* | 4.37 | 2.71 | 58 | 8 | 12 | 23 | 0 |
| 48 | *non esistono piu` le mezze stagioni* | 4.44 | 2.02 | 58 | 12 | 15 | 15 | 0 |
| 49 | *in quattro e quattr'otto* | 3.06 | 2.30 | 58 | 9 | 0 | 33 | 0 |
| 50 | *sulla punta della lingua* | 4.20 | 1.81 | 58 | 3 | 21 | 18 | 0 |
| 51 | *occhio per occhio* | 3.58 | 2.41 | 56 | 16 | 13 | 16 | 0 |
| 52 | *essere sopra ogni sospetto* | 4.88 | 3.01 | 54 | 19 | 15 | 12 | 0 |
| 53 | *dare nell'occhio* | 1.91 | 0.89 | 54 | 46 | 0 | 0 | 0 |
| 54 | *avere le mani in pasta* | 3.14 | 3.11 | 53 | 19 | 28 | 0 | 0 |
| 55 | *incrociare le dita* | 6.31 | 4.21 | 52 | 14 | 31 | 3 | 0 |
| 56 | *alzare il gomito* | 5.52 | 3.44 | 50 | 18 | 29 | 3 | 0 |
| 57 | *pecora nera* | 2.32 | 0.88 | 50 | 15 | 19 | 15 | 0 |
| 58 | *mani in alto* | 3.69 | 2.51 | 49 | 34 | 11 | 6 | 0 |
| 59 | *radere al suolo* | 2.95 | 2.69 | 48 | 17 | 28 | 3 | 3 |
| 60 | *fare un buco nell'acqua* | 3.75 | 2.24 | 48 | 26 | 22 | 4 | 0 |
| 61 | *scoppiare di salute* | 3.90 | 2.89 | 47 | 19 | 22 | 13 | 0 |
| 62 | *marcare stretto* | 5.74 | 3.84 | 47 | 23 | 30 | 0 | 0 |
| 63 | *due pesi due misure* | 5.24 | 3.68 | 46 | 15 | 31 | 8 | 0 |
| 64 | *bianco natal* | 5.35 | 3.29 | 46 | 8 | 35 | 8 | 4 |
| 65 | *luna calante* | 4.81 | 2.90 | 45 | 18 | 33 | 3 | 0 |
| 66 | *andare nel pallone* | 4.44 | 2.46 | 43 | 35 | 17 | 4 | 0 |
| 67 | *ammazzacaffe`* | 5.31 | 3.61 | 41 | 14 | 34 | 10 | 0 |
| 68 | *mettere il carro davanti ai buoi* | 4.50 | 3.45 | 40 | 27 | 23 | 10 | 0 |
| 69 | *farsi in quattro* | 4.80 | 3.09 | 35 | 15 | 46 | 4 | 0 |
| 70 | *leggere tra le righe* | 5.29 | 3.31 | 31 | 23 | 35 | 12 | 0 |
| 71 | *essere al verde* | 2.79 | 1.11 | 29 | 50 | 18 | 3 | 0 |
| 72 | *fare quattro salti* | 3.97 | 1.72 | 29 | 37 | 20 | 11 | 3 |
| 73 | *non vedere l'ora* | 5.02 | 4.04 | 21 | 17 | 62 | 0 | 0 |
| 74 | *ridere tra i denti* | 9.00 | 4.09 | 18 | 18 | 64 | 0 | 0 |
| 75 | *ampliare gli orizzonti* | 3.02 | 0.53 | 17 | 35 | 39 | 9 | 0 |
| 76 | *blu dipinto di blu* | 9.64 | 4.08 | 14 | 45 | 31 | 7 | 3 |
| 77 | *senza capo ne` coda* | 7.88 | 4.60 | 14 | 21 | 55 | 10 | 0 |
| 78 | *tenere sulla corda* | 1.82 | 1.09 | 11 | 69 | 6 | 14 | 0 |

## **Appendix 4** (continued)

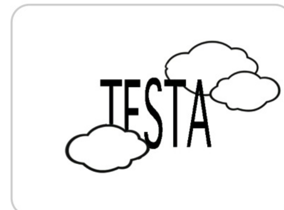
| RP Items | Solutions | Mean Solution Time (sec) | SD | % of Participants Solving Item | Errors | Timeouts | Answers Typed in More than 15 sec | No Answers |
|---|---|---|---|---|---|---|---|---|
| 79 | *essere o non essere* | 9.51 | 2.11 | 10 | 14 | 76 | 0 | 0 |
| 80 | *rompere gli indugi* | 5.81 | 5.69 | 10 | 55 | 31 | 0 | 3 |
| 81 | *mandare a monte* | 4.60 | 2.22 | 9 | 34 | 56 | 0 | 0 |
| 82 | *essere in testa* | 10.10 | 3.71 | 9 | 46 | 34 | 11 | 0 |
| 83 | *non sapere che pesci pigliare* | 3.16 | 0.45 | 7 | 27 | 57 | 10 | 0 |
| 84 | *avere le borse sotto gli occhi* | 5.94 | 0.00 | 4 | 27 | 58 | 12 | 0 |
| 85 | *fare fuori* | 9.82 | 0.00 | 3 | 33 | 60 | 0 | 3 |
| 86 | *guardare al/trovare il pelo nell'uovo* | 11.11 | 0.00 | 3 | 3 | 93 | 0 | 0 |
| 87 | *tutto sommato* | 3.50 | 0.00 | 3 | 51 | 40 | 6 | 0 |
| 88 | *mischiare le carte* | 0.00 | 0.00 | 0 | 74 | 26 | 0 | 0 |

**Appendix 4** reports the RPs used, their mean solution times of response and the respective standard deviation, the percentages of participants solving each item, errors, timeouts, answers typed in more than 15 seconds and items which did not receive any answers. The RPs are sorted from the higher percentage of solution to the lowest. The corresponding stimuli are reported in Appendix 5.

**Appendix 5** – Rebus Puzzle Items


1. **Solution:** *due di picche*


2. **Solution:** *tagliare la corda*




3. **Solution:** *avere la testa tra le nuvole*


4. **Solution:** *meno male*


5. **Solution:** *maglione*


6. **Solution:** *acqua in bocca*


7. **Solution:** *pan di stelle*


8. **Solution:** *chiave inglese*


9. **Solution:** *cantar vittoria*


10. **Solution:** *piove sul bagnato*


11. **Solution:** *avere il sangue blu*


12. **Solution:** *tra il dire e il fare c'e` di mezzo il mare*

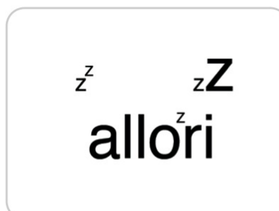
**Appendix 5** (continued)


**13. Solution:** *latte alle ginocchia*


**14. Solution:** *avere le braccine corte*


**15. Solution:** *mettere radici*


**16. Solution:** *non aver peli sulla lingua*



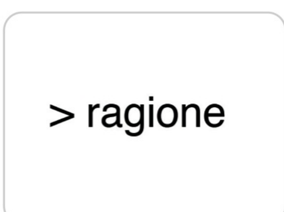

**17. Solution:** *dormire sugli allori*


**18. Solution:** *attimo fuggente*


**19. Solution:** *asso nella manica*


**20. Solution:** *ne` carne ne` pesce*


**21. Solution:** *una rondine non fa primavera*



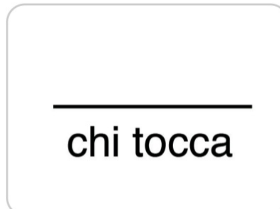

**22. Solution:** *a maggior ragione*


**23. Solution:** *bruciare le tappe*


**24. Solution:** *orche-stra*

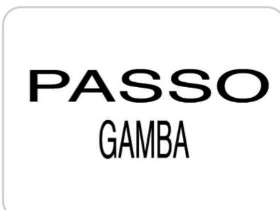
**Appendix 5** (continued)


**25. Solution:** *pan di spagna*

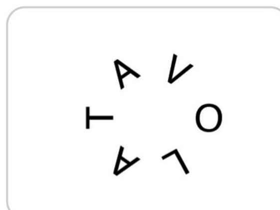



**26. Solution:** *sotto a chi tocca*


**27. Solution:** *fare le ore piccole*




**28. Solution:** *fare il passo piu` lungo della gamba*



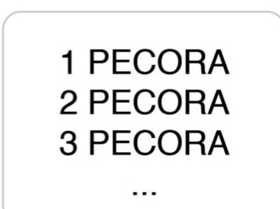
**29. Solution:** *tavola rotonda*


**30. Solution:** *essere di manica larga*


**31. Solution:** *mettere la mano sul fuoco*

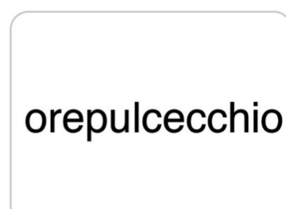

**32. Solution:** *darci dentro*


**33. Solution:** *avere le mani bucate*



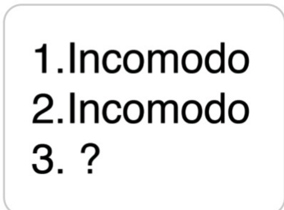

**34. Solution:** *contare le pecore*

**35. Solution:** *mettere i puntini sulle i*




**36. Solution:** *mettere/avere la pulce nell'orecchio*

**Appendix 5** (continued)

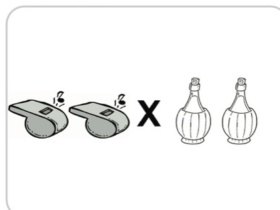



**37. Solution:** *terzo incomodo*

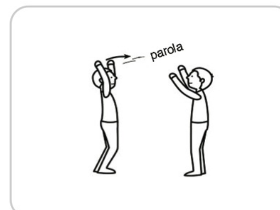

**38. Solution:** *pane al pane vino al vino*


**39. Solution:** *calcio d'angolo*


**40. Solution:** *il tempo vola*

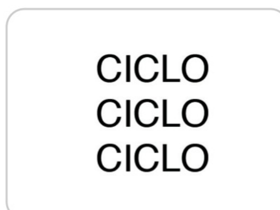



**41. Solution:** *prendere fischi per fiaschi*

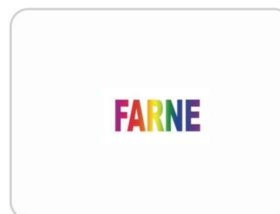



**42. Solution:** *passaparola*


**43. Solution:** *andare a nozze*



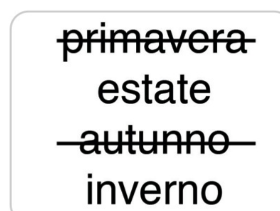

**44. Solution:** *triciclo*




**45. Solution:** *farne di tutti i colori*

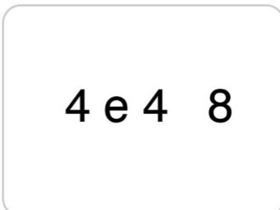

**46. Solution:** *avere le mani nel sacco*


**47. Solution:** *cercare un ago in nel pagliaio*




**48. Solution:** *non esistono piu` le mezze stagioni*

**Appendix 5** (continued)

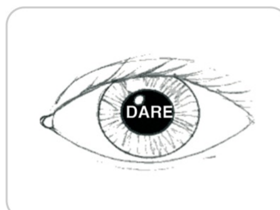



**49. Solution:** *in quattro e quatr'otto*


**50. Solution:** *sulla punta della lingua*

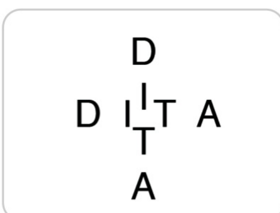

**51. Solution:** *occhio per occhio*


**52. Solution:** *essere sopra ogni sospetto*

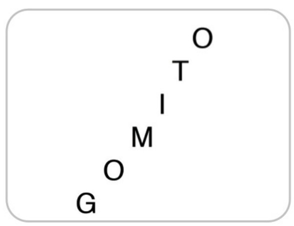



**53. Solution:** *dare nell'occhio*

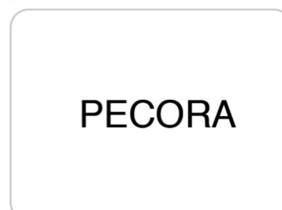

**54. Solution:** *avere le mani in pasta*




**55. Solution:** *incrociare le dita*




**56. Solution:** *alzare il gomito*




**57. Solution:** *pecora nera*


**58. Solution:** *mani in alto*

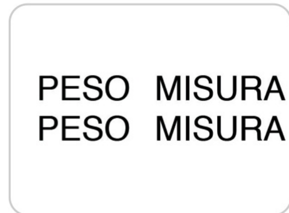

**59. Solution:** *radere al suolo*


**60. Solution:** *fare un buco nell'acqua*

**Appendix 5** (continued)


**61. Solution:** *scoppiare di salute*


**62. Solution:** *marcare stretto*

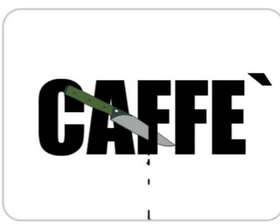



**63. Solution:** *due pesi due misure*


**64. Solution:** *bianco natal*


**65. Solution:** *luna calante*


**66. Solution:** *andare nel pallone*

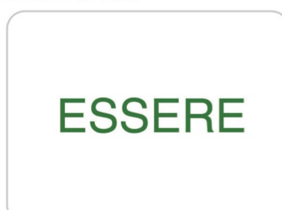



**67. Solution:** *ammazzacaffe`*


**68. Solution:** *mettere il carro davanti ai buoi*


**69. Solution:** *farsi in quattro*


**70. Solution:** *leggere tra le righe*

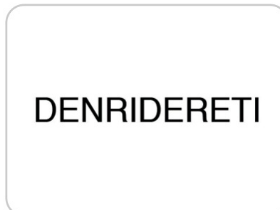



**71. Solution:** *essere al verde*

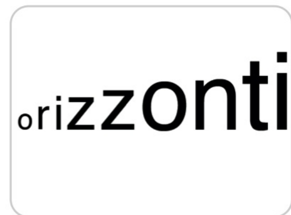

**72. Solution:** *fare quattro salti*

## **Appendix 5** (continued)

**73. Solution:** *non vedere l'ora*




**74. Solution:** *ridere tra i denti*

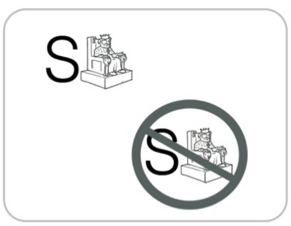



**75. Solution:** *ampliare gli oriz-zonti*

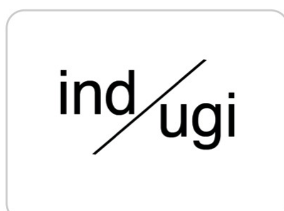

**76. Solution:** *nel blu dipinto*


**77. Solution:** *senzacapo ne` coda*

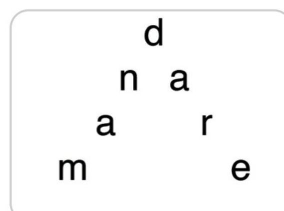

**78. Solution:** *tenere sulla corda*



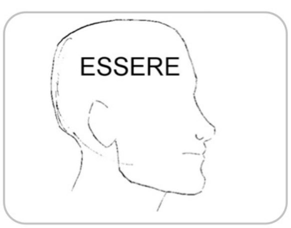

**79. Solution:** *essere o non essere*



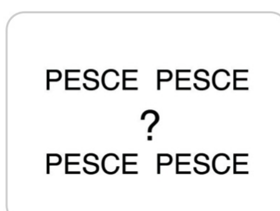

**80. Solution:** *rompere gli in-dugi*



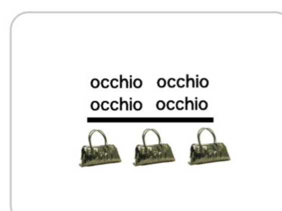

**81. Solution:** *mandare a monte*




**82. Solution:** *essere in testa*

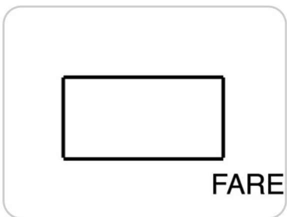



**83. Solution:** *non sapere che pesci pigliare*

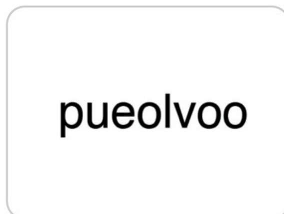



**84. Solution:** *avere le borse sotto gli occhi*

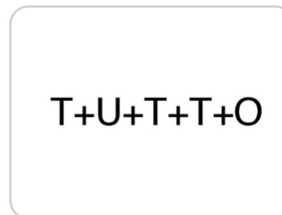
**Appendix 5** (continued)




**85. Solution:** *fare fuori*




**86. Solution:** *guardare al/ trovare il pelo nell'uovo*




**87. Solution:** *tutto sommato*


**88. Solution:** *mischiare le carte*

**Appendix 4** shows all the Rebus Puzzle items used to validate the test. The Rebus Puzzles are sorted from the higher percentage of solution.

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