論文 / 著書情報
Article / Book Information

題目(和文)	段階的変化法を用いた隠し絵におけるアハ体験から洞察を得る
Title(English)	Gaining Insight into an "Aha!" Experience of Hidden Figures in Gradual Change Paradigm
著者(和文)	石川哲朗
Author(English)	Tetsuo Ishikawa
出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第11212号, 授与年月日:2019年5月31日, 学位の種別:課程博士, 審査員:山村 雅幸,三宅 美博,小野 功,青西 亨,長谷川 晶一
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第11212号, Conferred date:2019/5/31, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Type(English)	Doctoral Thesis

Gaining Insight into an "Aha!" Experience of Hidden Figures in Gradual Change Paradigm

Tetsuo Ishikawa

A dissertation submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy (Science)

at the

Department of Computational Intelligence and Systems Science,

Interdisciplinary Graduate School of Science and Engineering,

Tokyo Institute of Technology

March/April 2019

Allting blir svårt när man vill äga saker, bära dem med sig och ha dem.

Jag bara tittar på dem och när jag går min väg har jag dem inne i huvudet

och kan ha roligare saker för mig än att bära kappsäckar.

Snusmumriken ur "Kometen kommer" Tove Jansson (1968)

Abstract

Once people perceive what is in the hidden figure such as Dallenbach's cow and Dalmatian, they seldom seem to come back to the previous state when they were ignorant of the answer. This special type of learning process can be accomplished in a short time, with the effect of learning lasting for a long time (visual one-shot learning). Although it is an intriguing cognitive phenomenon, the lack of the control of difficulty of stimuli presented has been a problem in research. In Study 1, we propose a novel paradigm to create new hidden figures systematically by using a morphing technique. Through gradual changes from a blurred and binarized two-tone image to a blurred grayscale image of the original photograph including objects in a natural scene, spontaneous one-shot learning can occur at a certain stage of morphing when a sufficient amount of information is restored to the degraded image. A negative correlation between confidence levels and reaction times is observed, giving support to the fluency theory of one-shot learning. The correlation between confidence ratings and correct recognition rates indicates that participants had an accurate introspective ability (metacognition). The learning effect could be tested later by verifying whether or not the target object was recognized quicker in the second exposure. The present method opens a way for a systematic production of "good" hidden figures, which can be used to demystify the nature of visual one-shot learning. Metacognitive processes of the eureka moment of an "aha!" is one of the keys to understand human subjective experience. However, the behavioral characteristics of this introspective cognition are not well known. An aha experience sometimes occurs when one gains a solution abruptly in problem solving, a subjective experience that subserves conscious perception of an insight. We experimentally induced an aha experience in a hidden object recognition task, and analyzed whether this aha experience was associated with metacognitive judgments and behavioral features. In Study 2, we show that intensities of the aha feeling is positively correlated with subjective rating scores of both suddenness and pleasure, features that show marked signs of unexpected positive emotions. The strength of the aha experience is also positively correlated with response times from the onset of presentation until finding the solution, or with task difficulty only if the solution confidence is high enough. In Study 3, we further analyzed the phenomenology of aha experiences. Our findings provide metacognitive, temporal and affective conditions for an aha experience, characterizing features distinct from those supporting non-aha experience.

Acknowledgments

I would like to profoundly thank Dr. Ayako Onzo, Ms. Mayumi Toshima, Ms. Tsugumi Takano, and Dr. Kei Omata for invaluable comments on the manuscript. I also express my gratitude Mr Shinichi Nozawa, Dr. Yuki Sato, Mr. Kazeto Shimonishi, Dr. Shiro Yano, Dr. Masato Abe, Dr. Iori Tani, Dr. Hisashi Murakami, Dr. Tomomitsu Herai, Dr. Eiichi Hoshino, Ms. Fumiko Tanabe, Dr. Takayasu Sekine, Dr. Tamami Sudo, Dr. Yuta Ogai, Dr. Keisuke Suzuki, Dr. Toru Yanagawa and Dr. Fumihiko Taya for their helpful discussion. I wish to thank Ms Haruna Takagawa, Ms. Miki Kato, Ms. Marie Mochizuki, Ms. Mai Kiyokawa, Mr. Kenji Aoki, Mr. Moko Asada, Ms. Fumi Okubo, Mr. Daiki Takahashi, Mr. Shigemi Sawa, Mr. Hisayuki Nagashima, Mr. Takumi Ueda, Dr. Masahiro Hasunuma, Mr. Yuta Chikauchi, Mr. Hiroshi Sugimoto, Ms. Yuka Kishimoto, and Mr Atsushi Sasaki for studying cognitive neuroscience together and teaching me various things.

I would also like to express great appreciation to Prof. Isao Ono, Prof. Toru Aonishi, Prof. Shoichi Hasegawa, Prof. Yoshihiro Miyake, Prof. Yasuharu Koike, Prof. Hiroyuki Nakahara, Prof. Atsushi Yoshikawa, Prof. Kiyohiko Nakamura, and Prof. Masayuki Yamamura for their practical comments and constructive discussion on my research.

I am very grateful that I have been able to work with and be stimulated by wonderful colleagues, Prof. Yuko Yotsumoto, Dr. Yoshiaki Someya, Dr. Kaoru Amemiya, Dr. Tomohiro Ishizu, Ms. Yui Takahashi, Prof. Noriko Kando, Mr. Victors Garkavijs, Ms. Rika Okamoto, Dr. Pawitra Chiravirakul, Ms. Diana Krusteva, Ms. Noriko Hayashi, Mr. Muneyoshi Otsuka, Ms. Mayumi Kusunose, Mr. Koichi Ashizaki, Dr. Ayano Fukushima, Dr. Hiroshi Kawasaki, Dr. Ichiro Miki, Dr. Kazuhiro Sakurada, and Prof. Eiryo Kawakami. I also sincerely thank my family and my old friends, Mr. Yutaka Moriyama, Mr. Akira Iino, and Mr. Satoshi Chida for their untiring encouragement and supports.

Finally, I would like to express deepest gratitude Prof. Takashi Ikegami, Prof. Yukio-Pegio Gunji, Dr. Yoshi Tamori, Dr. Ilya Farber, Mr. Ken Shiotani, and Dr. Ken Mogi for their unique views and advices: They inspired me towards a way of life in keeping doing science, arts and philosophy.

Contents

List of Tables

List of Figures

List of Abbreviations

ANOVA	analysis of variance
aPFC	anterior prefrontal cortex
AUC	area under the curve
CA	correct answer
CI	confidence interval
EFA	exploratory factor analysis
FA	false alarm
fps	frames per second
GCP	Gradual Change Paradigm
IA	incorrect answer
IQR	interquartile range
KG	Kaiser–Guttman
KM	Kaplan–Meier
LMM	linear mixed model
ML	morphing level
%ML++/sec	percent morphing level increment per second
ML1/ML2/ML3	factors estimated by maximum likelihood method
ml1/ml2	subfactors estimated by maximum likelihood method
NCP	No Change Paradigm
PFC	prefrontal cortex
Q1/Q2/Q3/Q4	first/second/third/fourth quartile
RCP	Rapid Change Paradigm
ROC	Receiver Operating Characteristic
RT	reaction/response/recognition time
rTMS	repetitive transcranial magnetic stimulations

SD	standard deviation
SEM	standard error of the mean
TOT	tip-of-the-tongue phenomenon
WTR	willingness to recommend
zConf.	z-scored Confidence rating

Chapter 1:
Introduction

The main theme of this thesis is gaining insight into an “Aha!” experience and its cognitive background. This thesis consists of three main studies on one-shot learning, aha experiences, and the phenomenologies concerning with cognitive processes. First, hidden movies created by morphing a hidden figure and its original counterpart can induce one-shot learning confirmed with enhance effects as response differences between the first sight and the second sight (Study 1). Secondly, a study is conducted on the factors that determine the strength of aha: suddenness, pleasure, and the interaction between confidence and solution timing (Study 2). Finally, the phenomenology of aha is revealed through an experiment considering more diverging aspects of subjective feelings. The phenomenology consists of two main factors that are the affective and the cognitive components (Study3).

Cognitive findings are sometimes accompanied by particular experiences, just as, in ancient Greek, Archimedes exclaimed “eureka!” to express his delight of a scientific discovery. This phenomenon is called “aha!" experience (Gick and Lockhart 1995; Topolinski and Reber 2010; Webb *et al.*, 2018). In the context of problem solving and creative thinking, “aha!” or “eureka!” experience is thought to be a synonym of insight (Weisberg 2015), defined as a sudden change in knowledge representation or the rapid formation of a new concept, often leading to the solution of a problem (Kounios and Beeman 2014). This insight frequently elicits a burst of various emotions (Shen *et al*. 2016), including a positive surprise at either the content or the way of realization. Solution accuracies with aha experience tend to be higher than those without aha (Webb *et al*. 2016; Salvi *et al*. 2016; Danek *et al*. 2017). Unexpected transition from disfluency to fluency, or abrupt switch from incorrect solution into correct solution tend to induce stronger aha experience. Social psychologist Robert Cialdini described the tendency as follows: "the *Aha!* experience is much more satisfying when it is preceded by the *Huh?* experience" (Heath and Heath, 2007; Webb *et al*., 2019).

A typical example of such irreversible cognitive processes of one-shot learning is the visual object recognition in hidden figures. The hidden figure consisting of a grayscale or black-and-white high contrast ambiguous picture such as "Cow" (Dallenbach 1951) and "Dalmatian" (Gregory 1970) seems to be meaningless blobs (Ishizu 2013) or meaningful but nonholistic pareidolias (Taylor *et al*. 2017) for naïve viewers. Once the viewers realize what is concealed in the hidden figure with appropriate disambiguation (e.g., interpretation in a sensible way; Hegdé and Kersten 2010; Ishizu 2013), sometimes an insightful "aha!" moment comes with a pleasant sensation.

It is necessary to establish the experimental method to induce one-shot learning in hidden figures. In order to achieve that, there were two problems: one was that there were few suitable hidden figures for the experiments and moreover these stimuli cannot be used repeatedly for the same participants. Another was that the efficient methods to examine learning processes of aha experiences did not exist. Therefore, we developed a new method to solve those problems (Ishikawa and Mogi 2011). The name of the method is Gradual Change Paradigm in hidden figures. The purpose of this thesis is to clarify the factors to influence on the strength of aha experiences in hidden figures using Gradual Change Paradigm.

Chapter 2:
Aha experience and one-shot learning (Related works)

2.1 Historical and Anecdotal Description of Insightful Moments

Many animals, including humans, exhibit creative abilities to solve open-ended problems in an innovative, unexpected, and ingenious manner. German gestalt psychologist Wolfgang Köhler (1917) called it *einsicht* (insight or intuition). Almost in the same era, Karl Bühler (1907) applied the word *Aha-erlebnis* ("Aha!" experience) to the subjective and affective experience (Gick and Lockhart 1995).

Figure 2.1 (A) Greek philosopher Archimedes in his bath (Author unknown), (B) Sapling of the reputed original tree that inspired Sir Isaac Newton to consider gravitation (Loodog 2014), (C) Ouroboros-benzene image (Haltopub 2013) appeared in Friedrich August Kekulé's dream. All images from Wikimedia Commons

There are plenty of anecdotes about the historic moment of creativity of the scientific discoveries: the "*Eureka"* moment of Archimedes (Fig. 2.1A) who exclaimed so twice to express his delight in discovery of the law of buoyancy by seeing an overflowing bathtub (Vitruvius, ca. 27 B.C.). Newton's apple (Fig. 2.1B) in discovery of the law of gravity (Stukeley 1752). Kekulé's dream of the Ouroboros (Fig. 2.1C) which gave him an inspiration of the Benzene ring structure (Kekulé 1890). There are many additional examples (Horvitz 2002). It would be noteworthy that there was a quite fascinating coincidence in the above list: all of these ideas were based on visual and graphical images.

These kinds of moments are not the privilege of the geniuses: ordinary people also have such insightful moments in daily life. Since most of the underlying processes that induce the instantaneous insight problem solving are unconscious and often intuitive (e.g., sensibility) (Volz and von Cramon 2006; Gigerenzer 2007), it seems quite different from conscious and gradual processes such as deliberate thinking and analytic solution (i.e., logic) (Morewedge and Kahneman 2010). However, cognitive mechanism and neural underpinnings of creative insight are not fully understood (see, e.g., recent reviews: Kounios and Beeman 2014; Shen *et al*. 2018).

2.2 Characterization of Insight Problem Solving

The insight solution in problem solving differs from the non-insight solution in several conspicuous points: (i) solvers experience their solutions as sudden and obviously correct (the Aha!). (ii) Prior to producing an insight solution solvers sometimes come to an impasse, no longer progressing towards a solution. (iii) Solvers usually cannot report the processing that enables them to overcome an impasse and reach a solution (Bowden *et al*. 2005). Sandkühler and Bhattacharya (2008) similarly summarized the features of insight in four keywords as "suddenness", "deeper understanding", "mental impasse", and "restructuring".

In the context of problem solving and creative thinking, "Aha!" or "Eureka!"

experience is thought to be a synonym of insight (Weisberg 2015), defined as a sudden change in knowledge representation or the rapid formation of a new concept, often leading to the solution of a problem (Kounios and Beeman 2014). This insight frequently elicits a burst of various emotions (Shen *et al*. 2016), including a positive surprise at either the content or the way of realization.

The invention of general relativity and the proof of mathematical problems such as Fermat's last theorem or Poincaré conjecture, for example, probably met the criteria mentioned above. Thus, those challenges must have involved certain kinds of problem solving by insight.

To study insight experimentally, however, much easier problems like sentence comprehension tasks (Auble *et al*. 1979), anagrams (Bowden 1997; Aziz-Zadeh *et al*. 2009), riddles (Luo and Niki 2003) or compound remote associates problems (Jung-Beeman *et al*. 2004; Sandkühler *et al*. 2008) are frequently used. Note that these commonly-used insight problems are not visual, but verbal puzzles.

2.3 Accuracy Advantage and Metacognition of Aha

Solution accuracies with aha experience tend to be higher than those without aha (Webb *et al*. 2016; Salvi *et al*. 2016; Danek *et al*. 2017). The accuracy advantage of the aha is related to metacognition, i.e., meta-level processes of "cognition about cognition" or "knowing about knowing." Metacognitive feelings leading to the right answers with the aha could be characterized by two stages: metacognition before reaching the solution and metacognition after the eureka moment. In the field of insight problem solving, metacognitive sense about the psychological distance from a solution is often assessed by warmth rating, or "Feeling of Warmth" (FoW), applying thermal metaphor to express feelings of near and distant as "hot" and "cold", respectively (Metcalfe, 1986). When subjects have a certain metacognitive sense that "the solution is near" (i.e., high FoW) long before a solution moment or metacognitive feelings are gradually changing (i.e., gradual increase in the FoW) as to approach a solution, the answer is likely to be a false alarm, or wrong answer (Metcalfe, 1986), the solution accuracy tending to be low. In such cases, the solving process may be judged as a non-insight. On the other hand, when subjects have a characteristic metacognitive feeling (i.e., abrupt jump of the FoW from cold to hot) just at the moment of realization of an answer, the solution process may be judged as an insight (Metcalfe and Wiebe, 1987; Kizilirmak et al., 2018; but see also, Hedne et al., 2016; Laukkonen and Tangen, 2018).

In the brain, the metacognitive processes subserving confidence judgments are underpinned by rostrocaudal (i.e., anterior-to-posterior) gradient in the prefrontal cortex (PFC), while in the later stage of the perceptual decision making, the more anterior part of PFC is involved in the metacognitive processes, with anterior prefrontal cortex (aPFC) activities in particular contributing to the metacognition in confidence judgment tasks (Rahnev *et al*. 2016).

There are large individual differences in the metacognitive abilities to monitor self-performance in such perceptual judgment, correlating with the gray matter volume of aPFC (Fleming *et al*. 2010) and fine structures of the hippocampus (Allen *et al*. 2017). The neural basis of metacognition in simple visual perceptual judgment may be also used in confidence judgment in the aha experience involving more complicated hidden figures (Imamoglu *et al*. 2012).

2.4 Visual Aha Experience and One-shot Learning in Hidden Figures

In the field of visual perception, the famous two-tone image of a Dalmatian dog (Gregory 1970) and the grayscale picture of a cow (Dallenbach 1951) are difficult to recognize for the first time. These hidden figures, consisting of a grayscale or black-and-white high contrast ambiguous picture, seems to be meaningless blobs (Ishizu 2013) or meaningful but nonholistic pareidolias (Taylor *et al*. 2017), i.e., partially interpretable inconsistent image, for naïve viewers. But once the viewers realize what is concealed in the hidden figure with appropriate disambiguation (e.g., interpretation in a sensible way; Hegdé and Kersten (2010); Ishizu 2013), a rapid perceptual learning occurs and is completed in a very short time. The dramatic transition from an unconscious impasse to a conscious epiphany sometimes with a pleasant sensation of "aha" during hidden object recognition meets the requirements for insight. Thus, hidden figure perception is an instance of visual aha experience.

During such an experience of insight (Bowden *et al*. 2005), it is thought that synaptic connectivities are changed rapidly to form a new association (Hebb 1949). Therefore, insightful abrupt learning associates meaningless patterns to meaningful understanding to gain a new concept unknown before the learning. It is differentiated from mere memory formation: encoding, retaining, and retrieval of well-known objects or things. This learning effect is long lasting and also called the Eureka effect (Ahissar and Hochstein 1997).

From another perspective, it is known that cognitive processes accompanied by aha experiences typically result in stronger long-term memory ("memory advantage") than cases of solution without aha (Danek *et al*. 2013; Kizilirmak *et al*. 2016). After an insightful realization, the learned knowledge sometimes prevents subjects from going back to the previous naïve state. This unique type of learning is a long-term memory encoding of one-shot experience (Ludmer *et al*. 2011), or called "one-shot learning" (Mogi *et al*. 2005; Mogi and Tamori 2006 2007; Giovannelli *et al*. 2010; Ishikawa and Mogi 2011; Dudai and Morris 2013).

2.5 Generation Effect of Aha

If one suddenly reaches a plausible interpretation of the hidden figure on one's own competence, generating a solution with aha, one would typically have more positive emotions and create stronger memory about the solution than when aha occurs without generating the answer (Kizilirmak *et al*. 2016). The solutions with aha would be remembered better than those without aha (Danek *et al*. 2013).

Generating a solution in hidden figure perception is the process of spontaneously and consciously becoming aware of the answer. At that time, changes in the functional connectivity between the visual areas and prefrontal regions are demonstrated to be important for conscious visual object recognition (Imamoglu *et al*. 2012). Gamma band synchronous activities involve forming the holistic object percept (Castelhano *et al*. 2013). The amygdala activation level associated with induced insight during hidden figure recognition is correlated with memory performance one week later (Ludmer *et al*. 2011).

2.6 How to Make Hidden Figures

Almost all of making process of well-known hidden figures were kept secret or at least not documented. Historically, several psychological tests using hidden figures have been developed to study Gestalt perception such as completion or closure: Street Gestalt completion test (Street 1931), a new closure test (Mooney and Ferguson 1951), Gestalt completion task and Snowy pictures task (Ekstrom *et al*. 1976), and Waterloo Gestalt closure task (Bowers *et al*. 1990). In many cases, however, there is a lack of specific description about how to create these figures. In the case of Waterloo Gestalt closure task, there is a short statement that artists drew a series of stimuli based on their experience. The famous hidden figures of cow (Dallenbach 1951) and Dalmatian (Gregory 1970) are actually photographs: the former was a collection of Leo Potishman and the latter was taken by the photographer, R. C. James. The conditions for shooting these photos and other details are not known. A simple quantisation of photographic images almost always results in either too obvious or difficult to perceive images and do not induce insight (Mogi and Tamori 2006, 2007). It is still unknown how to make "good" hidden figures systematically without manual retouch based on heuristics (For further discussions, see Chapter 6).

2.7 Ecological Views of Hidden Figure Perception

Are hidden figures accidental pictures taken in somewhat nontypical setups and thus such stimuli that does not exist in nature? It is not necessarily the case. In other words, similar counterparts of the hidden figures can be actually observed in natural context, e.g., scotopic or night vision. Considerable cognitive efforts are needed to perceive surroundings in dim light by using scotopic vision, as color information is useless and spatial resolution is much lower than usual. To segregate the figure from its ground is difficult in these impoverished contexts. Mammals, birds and also insects need to judge shapes of objects by, for example, perceiving illusory contour (Nieder 2002). The ability to perceive illusory contour in partial occlusion or in dimly lit situation such as under the moonlight is biologically adaptive in natural surroundings, as it is advantageous to be able to detect species which mimic their environmental patterns (e.g., felid's camouflage patterns, Allen *et al*. 2011) as quickly as possible to flee from predators or to target prey. A visual system with such ability to uncover concealed objects is called an "anticamouflage device" (Ramachandran 1987). Originally the term "anti-camouflage device" referred only to illusory contour perception. The concept is also applicable to the situation of seeing hidden figures.

2.8 Neural Correlates of Hidden Figure Perception

Two-tone degraded images of human face are named Mooney faces (Mooney 1957).

In the insightful moment when subjects perceive Mooney faces, neural synchronization spreads over a large portion of the brain, which lasts for about 100 msec (Rodriguez *et al*. 1999). Such synchronization is thought to be related to some of the Gestalt rules and feature binding (Singer 2009) or a mechanism for transient functional neurocognitive connectivity (Werner 2009). In general, when “Mooney” objects (i.e., bi-level quantized images of various objects) and their original grayscale photographs are presented alternately, activities of inferior temporal and parietal regions are enhanced (Dolan *et al*. 1997). Activities in the early retinotopic cortex and foveal confluence are modulated by top-down interpretation as well as the ventral visual stream and the lateral occipital complex (Hsieh *et al*. 2010). Repetitive transcranial magnetic stimulations (rTMS) over the parietal cortex during presentation of the undegraded images disrupt the identification of the degraded counterparts 30 min later (Giovannelli *et al*. 2010). The activation of left amygdala predicts memory performance 1 week later in a similar paradigm (Ludmer *et al*. 2011), suggesting the importance of emotional aspects of one-shot learning.

Chapter 3:
Development of morphing gradual change paradigm in hidden figure research (Study 1)

3.1 Introduction for Study 1

Repetitive usage of the same hidden figure is essentially invalid, as each hidden figure can be only effective to a naïve subject. Thus, there is a shortage of a battery of controlled stimuli to be used in an experiment. Note that the stimuli used in almost all of the preceding imaging studies were too difficult for subjects to recognize by themselves. An often used practice, instead of waiting for realization on their own, is to present pairs of the problem (the degraded two-tone picture) and the solution (the original grayscale or color picture) alternately to provide an answer directly and immediately: "rapid change paradigm (RCP)" (Dolan *et al*. 1997; Hsieh *et al*. 2010; Giovannelli *et al*. 2010; Ludmer *et al*. 2011). However, learning processes with cognitive effort to try to solve a problem without seeing the hint or answer are impaired in the RCP. These studies therefore focused not on spontaneous (unsupervised) learning but on forced (supervised) learning. An induced insight is different from a spontaneous one (Ludmer *et al*. 2011). The unaided perception of "good" hidden figures like Dallenbach's cow or Gregory's Dalmatian is concerned with the latter, where learning process takes some time, from a few seconds to a few minutes or more. In some cases the realization takes place after quite a long time, e.g., hours to days. Practically finite experimental time makes it difficult to adopt the free exploration paradigm without time limit.

Here we present a novel procedure which enables production in quantity of hidden figures to clarify the behavioral characteristics of unsupervised visual one-shot learning. By morphing "Mooney" objects with the original grayscale images, figures of varied perceptual difficulties were produced. As a "happy medium" of previous paradigms, i.e., the alternate presentation (the answer is presented immediately) and the static presentation (presentation of a hidden figure as still image for a prolonged time), the technique presented here sets out to morph a hidden figure and its solution with intermediate images between them. The morphed sequence of images facilitates the subject's quasi-spontaneous one-shot learning in a short time.

We expected that the percentage of perceived responses indicated by button press before the end of the movie would be high enough in the present morphing method. The correct rate was predicted to be considerably larger than that of in the conventional static paradigm. Features of individual stimuli (reaction time, morphing levels necessary for perceiving objects, and correct rates) and their interrelationship were investigated. When the correct rates are on a comparable level, reaction time is usable as an index of the degree of difficulty. The spectrum of reaction time for individual movies is supposed to be broader, if the multifariousness of the visual world is reflected in the stimuli.

The fluency theory (Oppenheimer 2008) has been applied to insight (Topolinski and Reber 2010). It predicts that when a certain cognitive process is executed fluently, the confidence and belief of truth about the process become high, independently of the objective truth. The fluency theory applied to visual one-shot learning would predict that the reaction time as an objective index of fluency must be correlated with confidence levels in a negative manner. We also investigated the effect of repetitive presentations of the same stimuli to confirm the accomplishment of visual one-shot learning. Once one-shot learning has occurred, the learning effect is found to be long-lasting. The comparison between the first and the second exposures would confirm the basic "once and for all" nature of "one-shot" learning. If the one-shot learning has an adaptive function, reaction times should be shorter in the second time compared to the first. The confidence levels in the second exposure should be larger than that for the first time. Finally, we examined the relationship that bridges the objective and subjective aspects of one-shot learning. A positive correlation between the objective correct rates and the subjective confidence levels would suggest that the subjects could judge their internal states accurately by introspection, suggesting proper metacognitive abilities.

Through the variation of morphing and temporal transition parameters, we constructed an external means to control the perception of figures in the conscious domain. Morphing provides a means of dynamically probing into the cognitive processes of one-shot learning, as opposed to the typical static approaches of the conventional hidden figure research. The analysis of results shed light on the interaction of the search and memory recall processes involved.

3.2 Methods

3.2.1 Participants

Eight healthy adult volunteers (4 males, aged 25–31 years; mean age 28.8 years) took part in the experiment. Participants were all right-handed, and had normal or corrected-to-normal vision. They were all native Japanese speakers. Instructions by the experimenter and verbal reports by participants were provided in Japanese. All procedures were performed with the participants' informed written consent and in accordance with the protocols approved by the Brain and Cognitive Sciences Ethics Committee of Sony Computer Science Laboratories.

3.2.2 Stimuli

Thirty-two grayscale photographs (300 × 300 pixels) of commonly familiar objects were blurred with Gaussian filter (radius = 3 pixels) and binarized to make ambiguous two-tone images. Movies were made by the computer software MorphX 2.9.5 (Norrkross Software) to display the whole morphing sequence in 1% morphing transitions, from the degraded image (e.g., Fig. 3.1 leftmost column) to the blurred grayscale original (e.g., Fig. 3.1 rightmost column).

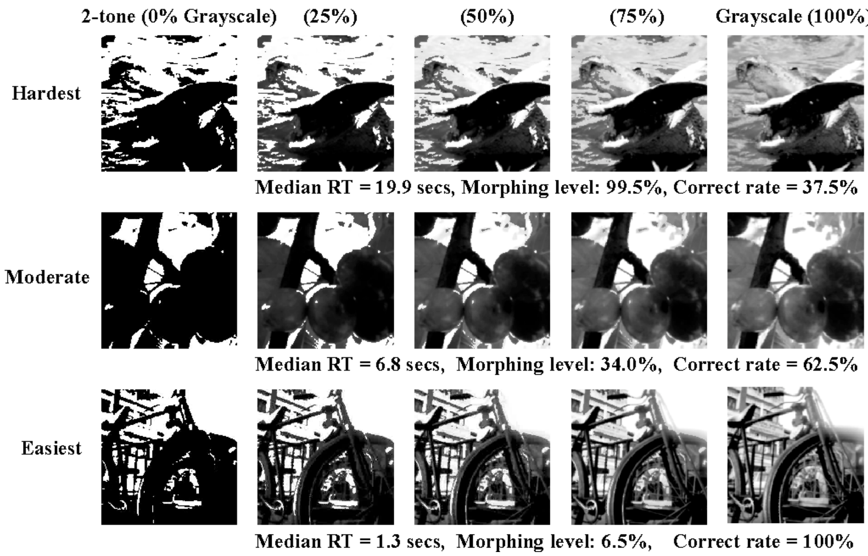

Figure 3.1 Typical frame examples extracted from the morphing movies. Top row: the hardest to perceive movie (''Alligator''), middle row: moderate difficulty movie (''Cherry''), and bottom row: the easiest to perceive movie (''Bicycle''). The median reaction time (RT), median morphing level and mean correct rate of these movies are set down underneath each figure. Difficulties of movies are assessed by the median reaction time, or the median morphing level. Time required for a half of participants to perceive is usable as index of difficulty unless more than a half of them time out (which was not the case for all stimuli in the present study). Therefore, the hardest movie meant the longest/highest RT/morphing level. The easiest one would be the stimulus with the shortest/lowest RT/morphing level. Moderate stimulus had an intermediate difficulty, i.e., the 15th RT/morphing level among all 30 stimuli. Reprinted by permission from Springer Nature: *Cognitive Neurodynamics*, Ishikawa and Mogi © 2011

The frame rate was 5 fps (1% morphing every 200 msec). The movie sequence consisted of 101 frames, with a total duration of 20.2 sec. The subjects sat in a comfortable position at a viewing distance of 60 cm from the computer display (Apple 13-inch MacBook). Stimuli (10° × 10°) were presented against a black background. We confirmed through enquiries after the sessions that all subjects saw all stimuli for the first time at the first exposure in this experiment.

The objects were selected from the list of "A Standardized Set of 260 pictures" (Snodgrass and Vanderwart 1980) which contained some familiar categories: insects, musical instruments, vegetables, fruits, animals, vehicles, carpenter's tools, etc.

3.2.3 Procedure

Subjects started watching movies on their own pace by clicking the mouse to extinguish a fixation cross and tried to perceive what was in the movie. They were instructed to stop the movie by clicking the mouse button and to shut their eyes when they recognized the object in it or when the movie was finished without recognition. The subjects were asked to close their eyes at the moment of realization, in order to prevent the inspection of the freeze-frame which remained on screen until the experimenter recorded the frame number of the movie and refreshed the display for the next trial. The subjects then verbally reported the name of the object and their "sureness" in a 11-point (0–10) scale. With the experimenter's verbal cue ("ready"), they opened their eyes and proceeded to the next trial (Fig. 3.2).

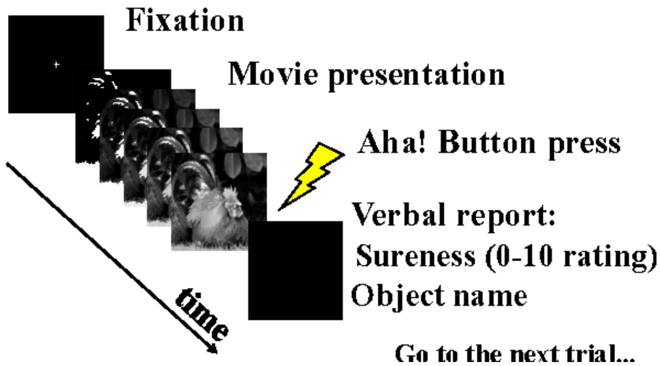

Figure 3.2 The time course of a single trial is depicted in illustrative manner. Until the moment that the subject presses the button, a morphing movie is played in an ascending fashion, from 0% of grayscale (two-tone) frame to 100% of grayscale one. The replay speed is 5 frames per second. All movies are constructed from 101 frames, with a maximum duration of 20.2 sec. After the key press or at the end of the movie, the participant was asked to report verbally the degree of confidence and what was perceived. For the movie in this figure, the correct answer was "Chicken." Reprinted by permission from Springer Nature: *Cognitive Neurodynamics*, Ishikawa and Mogi © 2011

The experiment was conducted twice after the practice session (two trials): In the initial exposure, thirty movies were played in a pseudorandom order. After a few minutes break, the same set of stimuli were presented in the same order in the second exposure. The interval for the presentation of the same stimulus was more than 15 min.

3.2.4 Statistical analysis

When no response occurs before the end of the movie, "reaction time" cannot be defined. In statistics, such a time- out trial is called a censored observation. To deal with the censored data properly, a survival (time to event) analysis with the Kaplan–Meier method (Bland and Altman 1998), which has been applied to the analysis of another domain of insight, i.e., matchstick problem (Chi and Snyder 2011), was conducted. A logrank test was used to compare the time to event curve. Regardless of whether participants responded or not in each trial, the answer for the movie (object name) and confidence rating were available. Hence the two-tailed paired/one-sample t-test, Pearson's correlation analysis, or two-way analysis of variance (ANOVA) was applied to the correctness of the answer (correct rate) and confidence data. The significance level was set to 0.05 for all statistical tests. Multiple comparisons are corrected by the Bonferroni method.

3.3 Results

The earlier frames of morphing movies were degraded and ambiguous so that the subjects found it hard to perceive what was in the frame. However, as the movie frames gradually got close to the original grayscale picture in the movie sequence, they could perceive something (either correctly or incorrectly) in the frame. Key press responses before reaching the end of morphing movies were observed in 92.0 ± 5.5% (mean ± SD) of trials in the first presentation. Significantly more reactions (95.4% ± 5.5% of trials) occurred in the second presentation ($t(7) = 2.65$, $p = 0.03$). Participants answered faster in the second exposure than the first exposure (first quantile: 15.8%, median: 35.5%, the third quantile: 69.3% for the first time and first quantile: 9.0%, median: 18.0%, the third quantile: 42.3% for the second time (logrank test: $\chi^2(1) = 20.5$, $p = 5.9\text{e}{-6}$). Verbal reports of the object name were judged by the experimenter to be either correct (correct answer, CA) or incorrect (incorrect answer, IA, including a non-perceived trial). Taking into account whether the answer was correct or not, 72.5 ± 9.7% of the movies were correctly perceived in the first exposure and significantly more 81.7 ± 6.2% of the movies were recognized aright in the second exposure ($t(7) = 3.67$, $p = 0.008$).

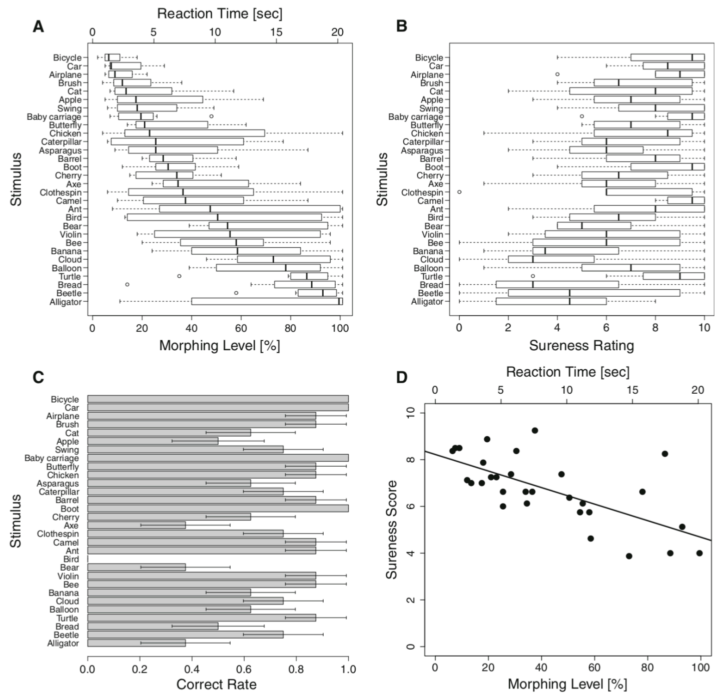

Figure 3.3 (A) The reaction times (upper abscissa) and morphing levels (lower abscissa) of individual movies in the first exposure are indicated in a box-whisker plot. The vertical bold line in a box indicates the median (i.e., the second quartile, Q2). The left and right sides of the box show the first quartile (Q1) and the third quartile (Q3), respectively. The left and right end of the whisker correspond to the minimum and maximum of the data in 1.5 times of interquartile range (IQR = Q3 - Q1) from Q1 or Q3, respectively. Blank circles show the data point outside the range of [Q1 - 1.5 IQR, Q3 + 1.5 IQR]. The movies are sorted by the ascending order of the median of response time from the top to the bottom of the graph. (B) The sureness scores of individual movies are shown in a box-whisker diagram. The alignment sequence of stimuli is the same as A. (C) The correct rate of answer object name is plotted for each stimulus in a barplot. The error bars indicate standard error of the mean. (D) The correlation between median morphing levels and mean sureness scores was significant (Pearson's correlation coefficient r = -0.67, p = 4.9e–05). Reprinted by permission from Springer Nature: *Cognitive Neurodynamics*, Ishikawa and Mogi © 2011

To elucidate the features in a variety of movies, the following analysis was conducted on individual stimuli using the data of the first exposure. Distributions of the morphing levels defined as percentages of containing grayscale picture (or RTs) at the time when participants perceived the hidden object were calculated for each movie and sorted by median RTs (Fig. 3.3A). In many cases, the distribution was not symmetric and had a fat tail in the right side. The sureness score (Fig. 3.3B) and the correct rate (Fig. 3.3C) were plotted in the same order as in Fig. 3.3A. The longer the subjects took to perceive, the less were confidence levels reported by them. (Fig. 3.3D). There was a significant negative correlation between median RTs (or morphing levels) and the mean sureness score ($r = -0.67$, $p = 4.9e\text{-}05$). The mean confidence ratings were correlated positively with mean correct rates ($r = 0.56$, $p = 0.0012$). Median RTs (or morphing levels), however, did not correlate with mean correct rates ($r = -0.36$, $p = 0.051$).

To compare the naïve observation (before learning occurred) with the second time one (when a learning might or might not have already occurred), the performance for a particular image was classified into four categories: IA–IA, IA–CA, CA–IA, and CA–CA conditions, based on the correctness of the subject's answer in the first and the second exposures. The probabilities of stimuli categorized for each condition were IA–IA: 15.8 ± 4.9%, IA–CA: 11.7 ± 8.3%, CA–IA: 2.5 ± 3.2% and CA–CA: 70.0 ± 12.0% of stimuli (mean ± SD). Time to event (IA or CA) curve analysis was conducted for the four conditions (Fig. 3.4). No significant difference was found between the curves of the first presentation and the second one in the IA–IA, IA–CA and CA–IA condition (logrank test: all *p*s > 0.05, Fig. 3.4A to C). On the other hand, only when the condition was the CA–CA one, the reaction time (or morphing level) was smaller in the second exposure than in the first exposure ($p < 0.001$, Fig. 3.4D).

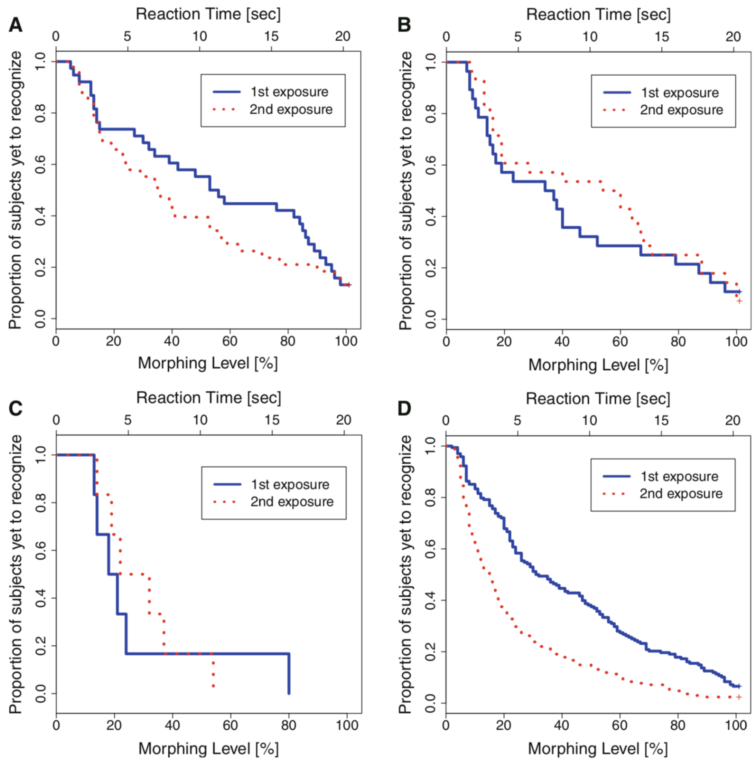

Figure 3.4 The time to event curves using Kaplan–Meier (KM) method are compared on exposure time. There are four conditions because of the combination of correctness (IA or CA) for each exposure time (1st or 2nd exposure). (A) IA–IA condition: when answers were incorrect in the first and the second exposure, the KM-curves are not significantly different (logrank test: χ^2 (1) = 0.7, p = 0.399). (B) IA–CA condition: when a correct perception occurred not for the first time but for the second time, a logrank test did not reveal significant difference between the first and the second exposure (χ^2 (1) = 0.3, p = 0.563). (C) CA–IA condition: when the answer changed to incorrect in the second exposure although the answer was correct in the first exposure, the time to event curves did not differ from each other (χ^2 (1) = 0.1, p = 0.741). (D) CA–CA condition: only in this condition, or when the answer in the second presentation was the same as the first correct one, the KM-curves of the second exposure dipped faster than that of the first one (χ^2 (1) = 35.2, p = 2.94e–09). Reprinted by permission from Springer Nature: *Cognitive Neurodynamics*, Ishikawa and Mogi © 2011

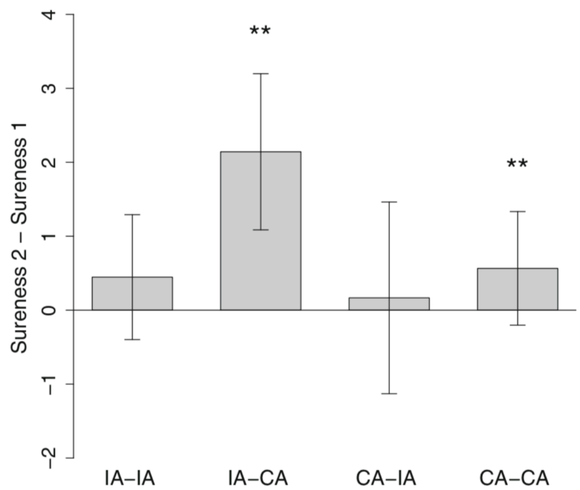

Figure 3.5 Difference of sureness ratings between the first and second presentations. In the IA–CA condition (two-tailed one-sample t test: $t(27) = 3.55$, $p = 0.0014$) and the CA–CA condition ($t(167) = 3.16$, $p = 0.0019$), the differences were significantly different from zero. In other words, sureness ratings were larger in the second exposure than in the first exposure. In the IA–IA condition ($t(37) = 1.08$, $p = 0.287$) and CA–IA condition ($t(5) = 0.10$, $p = 0.921$), a t-test did not reveal significant difference of sureness scores between the exposure time. Error bars show the standard error of the mean. Asterisks show the significance of p values adjusted in multiple comparison: ** $p < 0.01$. Reprinted by permission from Springer Nature: *Cognitive Neurodynamics*, Ishikawa and Mogi © 2011

Differences of sureness scores (i.e., ΔS = Sureness 2 - Sureness 1) indexed the change of confidence in the second exposure from the first time. ΔS was plotted for four experimental conditions (Fig. 3.5). If there is no change of sureness ratings, ΔS must be zero. To test the null hypothesis, one-sample *t*-tests were carried out. Significant differences from zero were yielded in the IA–CA and CA– CA conditions (*p*s < 0.01). For the rest, i.e., in the IA–IA and CA–IA conditions, the confidence levels were statistically unchanged (*p*s > 0.05).

There are two parameters which characterize the performance: subjective confidence and objective accuracy. The relationship between them is described in a line plot (Fig. 3.6).

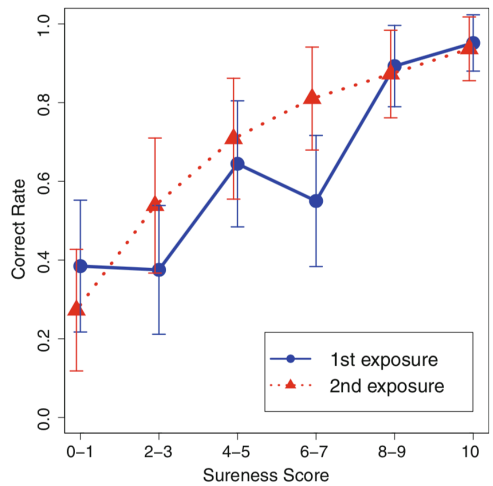

Figure 3.6 Correct rate as a function of sureness scores and number of exposures is shown in a line graph. The error bars represent the standard error of the mean. Two-way ANOVA (Sureness × Exposure) revealed that the main effect of sureness was significant ($F(5, 468) = 20.88$, $p = 7.47e{-}19$). The effect of exposure ($F(1, 468) = 0.398$, $p = 0.097$) and the interaction ($F(5, 468) = 0.32$, $p = 0.051$) were not significant. Correct rate and sureness rating are positively correlated in both the first exposure (Pearson's correlation coefficient $r = 0.93$, $p = 0.007$) and the second exposure ($r = 0.96$, $p = 0.003$). Reprinted by permission from Springer Nature: *Cognitive Neurodynamics*, Ishikawa and Mogi © 2011

The sureness data were summed up into six levels, because of the numbers of lower sureness scores were too small. To clarify the effect of sureness and the number of exposures on the correct rate, a two-way ANOVA was conducted. It showed the significant main effect of sureness ($p < 0.001$), whereas the effect of exposure ($p > 0.05$) and interaction ($p > 0.05$) were not significant. A correlation analysis was performed to examine the linear relationship between sureness and correct rate. Correct rate was positively correlated with sureness in both of the exposure times: Pearson's correlation coefficient $r = 0.93$ ($p = 0.007$) for the first exposure and $r = 0.96$ ($p = 0.003$) for the second exposure.

3.4 Discussion

The participants "perceived" some figures (irrespective of correctness) and responded in 92.0 ± 5.5% of stimuli in the first exposure before the end of the movie. Considering only the CA cases, 72.5 ± 9.7% of stimuli were perceived correctly for up to 20.2 sec of presentation in the first trial. It is significantly larger than that of the previous alternate presentation paradigm: for example, the spontaneous recognition rate was 27 ± 3% for up to 10 sec in experiment 2 of Ludmer *et al*. (2011). Moreover, in the conventional static presentation paradigm, where participants kept on searching a stationary hidden figure (Dallenbach 1951; Gregory 1970; Mogi *et al*. 2005; Mogi and Tamori 2006, 2007), the spontaneous recognition rate was relatively low. For instance, the correct rates of the famous hidden figures were 6.2% for "Cow" and 12.0% for "Dalmatian" after 300 sec in a series of mega-lab experiments with the number of subjects N = 113 (Mogi, Sekine and Tamori, unpublished data). In comparison, more than 70% of the stimuli were perceived correctly within a few tens of seconds in our study. Hence, it is suggested that the present study should provide a suitable method to investigate spontaneous one-shot learning rather than induced insight.

In the first exposures, the morphing levels necessary for cognition and the ratings for sureness for individual stimuli were negatively correlated. It is possible that the decline of confidence level as RTs (or morphing levels) became larger due to the decrease in the correct rate. However, this was not the case, because the RTs (or morphing levels) and correct rate were not significantly correlated in the first presentation. Therefore, the results support the fluency hypothesis of insight (Topolinski and Reber 2010), which predicts that a more fluent processing (i.e., the shorter RT) induces a more confident feeling in the subjects.

The morphing levels, or response time lengths can be thought of as indicators of the degree of difficulty for recognition of the objects. A higher sureness score would indicate a lower degree of difficulty, and hence a higher fluency. Individual stimuli used in the present study indicated a wide spectrum of RTs or morphing levels (Fig. 3.3). In turn, the battery of stimuli used reflected a wide range in the degree of difficulty. Neither too difficult nor too easy problems, but problems with a right degree of difficulty, are proposed to be one of the prerequisites for insight (Hebb 1949). A robust set of hidden figures with appropriate difficulty levels (i.e. "good" hidden figures) is needed to demystify the nature of one-shot learning, because a hidden figure can be used only once per a subject in an experiment. By applying the present method, new hidden figures with various difficulty levels can be made in a systematic manner.

The reaction time (or morphing level) of recognition at the second trials was smaller (or lower) than the first trial only in the CA–CA cases, suggesting that one-shot learning leads to an appropriate prior knowledge to be used in the next trial when participants perceived correctly in the naïve state. Once learning is accomplished in the right direction, it should be adaptive to save time in grasping the situation instantaneously using the "anti-camouflage" device to detect hidden objects without additional exploration.

Familiarity of objects' names were ensured by using the standardized stimuli set (Snodgrass and Vanderwart 1980). A complete list of all objects used in the experiment is provided in Fig. 3.3. Note that the initial letter of most words in English was A, B or C, apart from a few exceptions. In Japanese, however, names of objects started with varied phonemes. Therefore there was no chance that a certain type of phonological priming effect occurred accidentally.

The same stimuli order used in the first and second exposure might have led to the possibility of contextual effect or trial-to-trial dependencies. If such an effect occurred generally, time to event curves would have been different between the first and second exposures. However, this was not always the case. The change of time to event curve was only observed in the CA–CA condition. Although this analysis alone does not necessarily signify that there were no trial-to-trial dependencies of any kind, it does suggest that contextual effects, if any, had a limited impact on the main results.

The average rating of sureness in the second trial was higher than that in the first one in the IA–CA and the CA–CA conditions. For the former case, it is possible that the participants were aware of the incorrectness of their answers at the first exposure, reflected in the change to the correct answer at the second trial. For the latter case, it is possible that they became more confident because of the repetition of subjective feeling of certainty, or fluency.

There was a positive correlation between the rating of sureness and the correct rate. Thus, the subjective evaluations of confidence were consistent with the objective performance, providing a measure for metacognition. The scene consistency between the perceived figure and ground that ensures the accuracy of object recognition (Davenport and Potter 2004) may subserve the appropriate metacognition.

Humans can learn to recognize difficult Mooney faces after a brief (about 5 sec) exposure of unambiguous counterparts. Neurons in the inferior temporal cortex of primates exhibit an enhancement reflecting the neural substrate of the rapid perceptual learning (Tovee *et al*. 1996). A patient with anterograde amnesia (Korsakoff's syndrome) possibly caused by a medial temporal lobe damage showed no evidence of perceptual learning (Ramachandran 1995). Although his response time for the recognition of hidden figures was relatively normal, there was no reduction in latency when the same figures were exposed more than once. These evidences suggest that the inferior temporal visual cortex is involved in visual one- shot learning.

In sum, we proposed a novel paradigm to create new hidden figures with a broad spectrum of difficulty levels in a systematic manner by using a morphing technique. Through gradual changes from a blurred and binarized two-tone image to the blurred grayscale image of the original photograph including objects in a natural scene, spontaneous one-shot learning could occur at a certain stage of morphing when a sufficient amount of information is restored to the degraded image. A negative correlation between confidence levels and the reaction time or morphing level necessary for perceiving objects is consistent with the fluency theory of insight (Topolinski and Reber 2010) in the domain of visual one-shot learning. A strong correlation between the confidence ratings and the correct recognition rate indicates that the subjects had accurate metacognition. The comparison between the first and the second exposures confirms the basic “once and for all” nature of “one-shot” learning. The learning effect could be tested later by checking whether the target object is recognized quicker in the second exposure. The results reported here suggest a potential relationship between the underpinning mechanism of one-shot learning and the neural substrate of short-term (Rutishauser *et al*. 2010) or long-term (Ludmer *et al*. 2011) memory formation and retrieval. Thus, we note that memory components of one- shot learning is the result of the learning and not the other way around. Further sets of research are needed to clarify the reason why and how one-shot learning leads to long lasting memories based on just a single trial. The present method paves a new path for the production of “good” hidden figures in large quantities, which can be used to eventually demystify the nature of visual one-shot learning.

Chapter 4:
Metacognition and solution timing characterize aha experience (Study 2)

4.1 Introduction for Study 2

The previous Study 1 described in Chapter 3 did not explicitly measure any subjective indices of the phenomenological aspects of aha experience when investigating the neural correlates of object detection and recognition in hidden figures. The neural substrates of subjective aha feelings and its strength in hidden figure recognition are not well known. Successful cognitive strategies in generating answers and induce desirable aha experience are not yet clear.

A review of major experimental paradigms in previous studies would clarify several limitations of previous experiments with hidden figures as stimuli. The simplest method is to continue presenting a hidden figure as a still image until recognition (Imamoglu *et al*. 2012; Murata *et al*. 2014). In this "no change paradigm (NCP)", the task difficulty is not easy to adjust properly, as the process of utilizing the combination of blurring and thresholding to create a hidden figure often makes the image too hard or too easy to recognize. If the problem is too difficult to solve, the answer rate within a certain period of time decreases, while the responded data available to analyze also decreases (Ishikawa and Mogi 2011). On the other hand, if the problem is too easy, there is no stagnation ("impasse") in the first place, compromising the suitability as a problem-solving task (Salvi *et al*. 2016). Secondly, there is a more sophisticated method in which the stimulus image suddenly switches from a two-tone (hidden figure) to a grayscale ("answer") photograph after being presented for a certain predetermined duration (Dolan *et al*. 1997; Ludmer *et al*. 2011; Kizilirmak *et al*. 2016). In this "rapid change paradigm (RCP)", where the answer is directly exposed all of a sudden, the viewer can be forcedly made to recognize the answer. Although the RCP guarantees higher answer rate than in the case of the NCP, it eliminates or at least alleviates the cognitive processes of solving spontaneously without seeing the answer. Furthermore, the RCP would not facilitate investigations into conditions of the spontaneous occurrence and timing of aha. In sum, neither the NCP nor RCP provides a sufficiently robust method for studying aha experience in an experimentally tangible manner.

In order to solve these problems, an experimental methodology (Ishikawa and Mogi 2011) was developed by morphing black and white binarized images and grayscale images, generating images at intermediate stages, arranging them in order in frames and making them animated from the problem (hidden figure) toward the answer (grayscale "original"), thus producing a gradually changing stimulus (Gradual Change Paradigm, or GCP).

Major theories of aha experience have proposed two key aspects: (i) appropriate (desirable) difficulty (Hebb, 1949) and (ii) cognitive fluency (Topolinski and Reber, 2010; in more general context, see also, Oppenheimer, 2008). According to the appropriate difficulty theory, insight tends to occur when the problem is neither too easy nor too difficult. In other words, if the task is too difficult it is impossible to solve the problem, and if it is too easy there is no surprise. According to the fluency theory, even if the problem is difficult, if cognitive processes at the moment of solution is fluent, the solution with high confidence often tends to be correct, accompanied by positive emotions, or surprise "aha!". In line with the fluency theory, the assumption that confidence in insight solutions is greater than that of non-insight ones is sometimes called the confidence hypothesis (Danek *et al.*, 2014b). In the same vein, the supposition that accuracy of insight solutions is higher than that of non-insight ones is referred to as the accuracy hypothesis (Salvi *et al.*, 2016; Danek and Salvi, 2018).

In this experiment, to validate that insight would be induced by the GCP in hidden figures, we would confirm two auxiliary hypotheses from theories of insight,: (i) accuracy hypotheses (Salvi *et al.*, 2016; Danek and Salvi, 2018) predicting that insight solutions are more accurate than non-insight solutions and (ii) confidence hypothesis (Danek *et al.*, 2014b) predicting that "Participants' confidence in the correctness of their solution differs between insight and noninsight problem solving". After the validity checks, by combining appropriate (desirable) difficulty theory (Hebb, 1949) and cognitive fluency theory (Topolinski and Reber, 2010), we tested a main hypothesis that if the hidden figure problem is not too easy, and the final confidence is high enough, the high fluency at the insightful moment would induce a strong sense of aha accompanied by positive emotions. We confirm these hypotheses, shedding light on the conditions under which an aha experience would occur.

4.2 Methods

4.2.1 Participants

Ten naïve adults (six females and four males, mean ± SD age: 33 ± 6 years old) participated in the experiment. All participants had a normal or corrected-to-normal visual acuity. All procedures were performed with the participants' informed written consent and in accordance with the protocols approved by the Brain and Cognitive Sciences Ethics Committee of Sony Computer Science Laboratories.

4.2.2 Stimuli

Sixty-five movie stimuli were created by means of the morphing paradigm (Ishikawa and Mogi 2011). Each movie was constructed as follows. An 8-bit (0-255 levels) grayscale picture of common object(s) was cropped to 300 pixels × 300 pixels size, and blurred (Gaussian filter: radius = 3 pixels) and binarized (128 for the threshold value). The resultant figure was a black and white two-tone image, or a "Mooney image" (Mooney and Ferguson 1951; Mooney 1957). A morphing technique using the software Norrkross MorphX (Norrkross Software, Tynningö, Sweden) was applied to the Mooney image and its original blurred counterpart. Morphing levels (MLs) defined by the percentage of the blurred grayscale image in the fusion image was an index of degradation. Finally, one hundred and one degraded images (of MLs from 0 % to 100 %, with increments of 1 %) were converted into a movie with 101 frames in total. In the movie, frames were presented in the ascending direction from 0 % (Mooney image) to 100 % (blurred grayscale image). Example movie frames extracted from four representative stimuli are shown in Figure 4.1. All objects were selected from the normative set (Snodgrass and Vanderwart 1980).

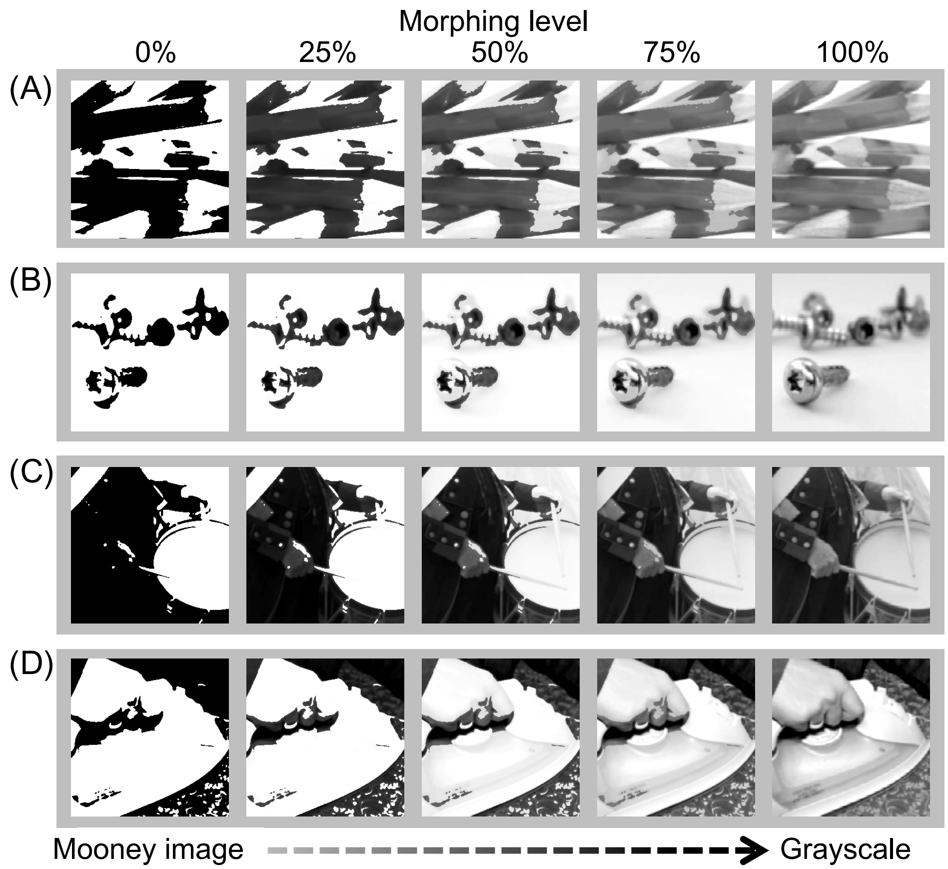

Figure 4.1 Movie frames of representative stimuli inducing strong aha (A, B) and weak aha feelings (C, D).

(A) The highest aha score (mean = 4.9) image with high confidence score (= 5.5) and long RT (mean ML = 98%). (B) Moderately high aha score (= 4.0) image with high confidence (= 5.6) and long RT (ML = 87%). (C) Fairly-low aha score (= 2.8) image with high confidence (= 5.7) and short RT (ML = 10.9%). (D) Considerably low aha score (= 2.7) image with low confidence (= 4.2) and relatively long RT (ML = 77.4%). Note that the morphing movie frames change from the left to right. Correct answers: (A) Pencils, (B) screws, (C) a drum, and (D) an iron

The frame rate of the movie was 10 fps (100 msec/frame) or 5 fps (200 msec/frame). The relevant measure of movie replay speed was percent ML increment per second

(%ML++/sec). The change speed of stimuli was 10 %ML++/sec or 5 %ML++/sec, with a total duration of 10.1 sec and 20.2 sec, respectively.

4.2.3 Procedure

The stimuli were presented on a 13-inch MacBook (Apple Inc., Cupertino, CA, USA) display against middle gray (128 level) background using MATLAB R2010a (The MathWorks, Inc., Natick, MA, USA) with Psychtoolbox (Brainard 1997; Pelli 1997). The participants were seated at a distance of 60 cm from the display. The trial timeline was as follows (Fig. 4.2).

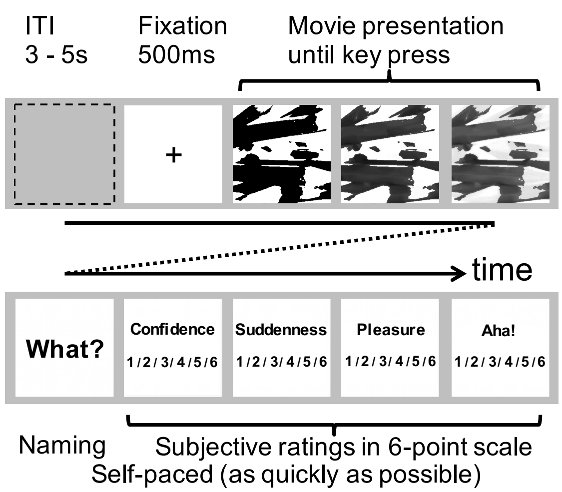

Figure 4.2 Experimental procedure denoting a single trial time course, consisting of two stages: The stimulus presentation phase (upper row) and the answering phase (bottom row). In the first stage, the participants were required to find hidden object(s) in the movie stimulus. When a "eureka" moment comes, they were instructed to indicate by the [SPACE] key press. In the second stage, after the "What was it?" message was displayed, the participants were asked to verbally report the object name and press the [SPACE] key to proceed. The confidence, suddenness, delight, and "aha!" ratings were reported in a six-point scale by selecting and pressing one of the [1] – [6] keys

The fixation cross ("+" mark) was shown for 500 msec at the start of each trial. After the fixation cue disappeared, the morphing movie (visual angle: $10° \times 10°$) presentation begun. The participants were instructed to press the [SPACE] key as quickly as possible when they recognized object(s) in the movie. We defined response or recognition times (RTs) as the time from the onset of movie presentation to the key press. When the participant pressed the [SPACE] key, the movie disappeared and the display flipped to the next answer step. When the last frame of movie disappeared, the trial continued to the next answer phase. The participants were required to report the object name verbally. Then they were also asked to provide subjective ratings (cf. Danek *et al*. 2017) in a six-point scale on four types of feelings: (i) Confidence: How sure are you about your solution? (ii) Suddenness: How suddenly did you find the answer?, (iii) Pleasure: How much pleasure did you get?, and (iv) Aha feeling: How strongly did you feel "aha!"? The order of subjective ratings was fixed throughout the experiment to reduce the cognitive demand. The inter-trial interval (ITI) was randomly selected from 3, 4, or 5 sec.

In the instruction phase preceding the practice trials, subjects were shown Dallenbach's Cow and Gregory's Dalmatian as typical examples of hidden figures inducing aha experiences, and asked to search for hidden objects. If they did not spontaneously recognize answer objects after a while, some hints on the location of objects and (if necessary) object names were provided one after another. If the subjects could not realize how and where objects were hidden after getting some clues, detailed explanation of answers was provided until they were convinced. After that, participants were told that the very experience when the object hidden in such a figure was suddenly and clearly understood was a typical aha experience. Subsequently, in the practice phase, subjects practiced to recognize objects in hidden morphing movies and judge strengths of subjective assessments on (i) aha feeling, (ii) confidence, (iii) suddenness, and (iv) pleasure. If they had any questions or requests for clarification, additional explanations were provided.

Five movies were used for the practice session, while the remaining sixty were reserved for the main experiment. The two alternative replay speeds (10 %ML++/sec or 5 %ML++/sec) were randomly assigned to half of the trials each and counterbalanced across the participants.

4.2.4 Statistical Analysis

To compare means for multiple groups, paired *t*-test or type III ANOVA with Kenward–Roger's method was used. By correcting the degrees of freedom, the latter method can handle missing cases (e.g., data from a participant with no incorrect answers) properly without information loss due to omission. In correlation analysis, Spearman's rank correlation coefficients (r_s) (which were suitable to estimate monotonic relationships, i.e., robust effect sizes of correlations by reducing possible spurious effects from outliers) and its 95 percent confidence intervals (95% CIs) were evaluated after averaging scores for each stimulus (by-item analysis).

We used the type-2 receiver operating characteristic (ROC) analysis suitable for measuring metacognition (Fleming *et al*., 2010; Fleming and Lau, 2014). In contrast with the type-1 ROC analysis, the type-2 ROC analysis is similar but meta-level analysis. In other words, the second-type ROC analysis is an analysis to quantify the precision of metacognition based on the degree of confidence and performance (i.e., accuracy). Fleming and colleagues (2010) stated that "Participants' confidence ratings were used to construct a type II ROC function that quantifies the ability to discriminate between correct and incorrect responses cumulated across levels of confidence." More specifically, the type-2 ROC curves are constructed from false positive and true positive defined by p(confidence | incorrect) and p(confidence | correct), respectively. Area under the type-2 ROC curve (AUC) was calculated as a measure of metacognitive precision.

In hierarchical regression, we built linear mixed model (LMM) with participants as random effect. In order to correct degrees of freedom in the LMM, we made the Kenward–Roger adjustment. We applied R lmerTest::lmer() function with post-hoc Tukey's all-pair multiple comparisons using the multcomp::glht() protocol. The model estimation was optimized in the same way as in Folke *et al*. (2016). The significance level of any statistical test was set to alpha = 0.05. For correction of multiple comparisons in both the comparisons between groups and the correlation analysis, p-values were adjusted by the Holm–Bonferroni method.

Post-hoc power analysis (Green and MacLeod 2016; Brysbaert and Stevens 2018) was carried out using simr::powerCurve() function to evaluate whether the sample size, i.e., the number of participants N = 10 was enough to detect an interaction effect between confidence and RT on aha feelings.

4.3 Results

Of the total 650 trials, "Recognized" responses of object naming were observed in 619 trials (mean ± SD = 95.2% ± 4.7%), while "Don't know" responses were recorded in the remaining 31 trials (4.8% ± 4.7%). Among "Recognized" responses, there were 580 trials (89.2% ± 5.8%) with correct answers and 39 trials (6.0% ± 4.7%) with wrong answers.

When examining the effect of the presentation change speed (Fast = 10%/sec vs. Slow = 5%/sec) on the Aha rating, the mean (± SEM) Aha score was not significantly different ($F(1, 9) = 0.17$, $p = 0.69$) between Fast (3.42 ± 0.29) and Slow (3.46 ± 0.31) trials. Therefore, in the following analysis, data from the Fast and Slow trials would be merged without considering the presentation speed difference. Since there was no need to distinguish speed differences, RTs could be measured by ML units. In other words, hereafter, RTs and MLs would be regarded as interchangeable.

Mean subjective ratings were compared between correct and incorrect responses by the Type III ANOVA with Kenward–Roger's degree of freedom correction. Aha scores were significantly higher ($F(1, 8.35) = 12.04$, $p = 0.032$) in correct trials (mean ± SEM = 3.52 ± 0.29) than in incorrect (2.22 ± 0.49) ones, suggesting that the accuracy hypothesis was correct.. Likewise, Pleasure (3.28 ± 0.28 vs. 2.08 ± 0.40, $F(1, 8.30) = 16.26$, $p = 0.014$), Suddenness (3.54 ± 0.28 vs. 2.29 ± 0.45, $F(1, 8.38) = 11.84$, $p = 0.033$), and Confidence (5.05 ± 0.25 vs. 2.64 ± 0.37, $F(1, 8.43) = 46.84$, $p = 0.0004$) ratings were significantly higher for correct responses than for incorrect ones (all *p*s reported here were corrected for multiple comparisons). Note that participants did not get any feedback about the correctness of answers during the trials. Although there were no external cues to confirm the correctness of answers, the subjects might have been able to accurately judge the likelihood of correct answer through the subjective feeling of correctness, as a subset of feelings related to metacognition. To investigate this possibility, we assessed the relationship between confidence and performance by type-2 ROC analysis (Fleming *et al*., 2010; Fleming and Lau 2014), which defines the precision of metacognition as an area under the type-2 ROC curve (AUC). The average AUC = 0.90 (95% CI = [0.81, 0.98]) was significantly higher ($t(9) = 10.47$, $p < 0.001$) than the chance level (i.e., 0.5 for random judgement).

In order to examine the relationship between performance and insight from another angle, we classified the solved trials into "insight" and "non-insight" to facilitate comparison with the previous research (Jung-Beeman *et al*., 2004; Danek *et al*., 2014a; Danek *et al*., 2014b) in which dichotomous categorization were used (see discussion for the details of which scales or categorization should be used). Here, for simplicity, insight and non-insight were defined by Aha ratings of 1-3 and 4-6, respectively. The accuracy hypothesis and the confidence hypothesis were verified. We compared the mean accuracy of insight solutions (mean ± SEM = 98.2 ± 1.27%) to the mean accuracy of non-insight solutions (89.8 ± 2.69%). A significant difference ($t(9) = 2.81$, $p = 0.02$) was found, suggesting that participants were more accurate in insight solutions than in non-insight solutions. We also found a significant difference ($t(9) = 7.26$, $p < 0.001$) between the mean Confidence rating of insight solutions (5.28 ± 0.20) and that of non-insight solutions (4.44 ± 0.27), indicating that participants had higher confidence in insight solutions than in non-insight ones.

In what follows, further analysis would deal with only the correct responses, as the number of incorrect responses was found to be statistically insufficient. In addition, further analysis would be performed by treating Aha ratings as continuous (ordered multilevel) values instead of dividing into insight/non-insight.

We carried out correlation analysis in an exploratory manner to elucidate interrelationship between subjective ratings (i.e., “Aha”, “Suddenness”, “Pleasure”, and “Confidence” scores) and an objective measure (i.e., MLs). Aha, Suddenness, and Pleasure were positively and strongly associated with each other (all r_ss > 0.7, multiple comparison adjusted ps < 0.001). Confidence was not correlated with Aha ($r_s = 0.20$, $p = 0.35$), but correlated with both Suddenness ($r_s = 0.37$, $p = 0.02$) and Pleasure ($r_s = 0.34$, $p = 0.03$). MLs had a positive association with Aha ($r_s = 0.33$, $p = 0.03$) and a negative impact on Confidence ($r_s = -0.52$, $p < 0.001$). Detailed results including effect sizes (i.e., magnitude of correlations) and its 95% CIs of the correlation analysis are summarized in Table 4.1.

Table 4.1 Spearman correlation matrix for subjective and objective measures

	Suddenness	Pleasure	Confidence	Morphing Level
Aha	0.78 *** [0.60, 0.89]	0.79 *** [0.61, 0.89]	0.20 [-0.11, 0.47]	0.33 * [0.03, 0.58]
Suddenness		0.72 *** [0.50, 0.85]	0.37 * [0.05, 0.59]	0.10 [-0.18, 0.37]
Pleasure			0.34 * [0.03, 0.59]	0.06 [-0.19, 0.3]
Confidence				-0.52 *** [-0.73, -0.23]

*p < 0.05, ***p < 0.001 two-tailed test vs. 0. Values inside the brackets represent 95% confidence intervals with correction for multiple comparisons

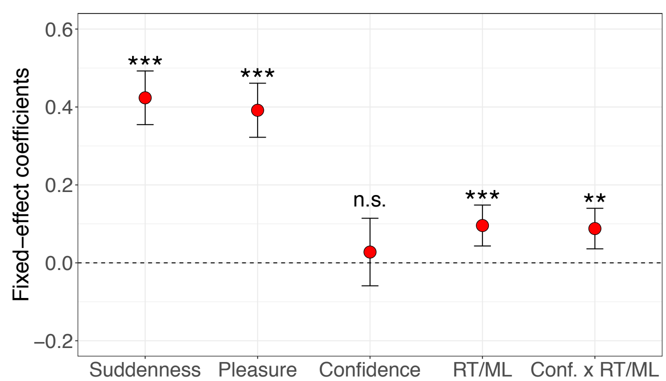

Figure 4.3 Factors contributing to the strength of aha feeling. Fixed-effect coefficients in hierarchical regression models that predict aha scores by utilizing linear mixed model (LMM) with participants as random effect. Error bars show the 95% CIs. n.s. stands for not significant, **p < 0.01, ***p < 0.001, two-tailed test vs. 0

Although the rank correlation analysis revealed bivariate monotonic relationships between each pair of indices, it could not necessarily reflect relative influence because it did not consider multivariate entanglements, e.g., interaction effects. Therefore, in the next step as a complementary analysis, we utilized LMMs with the participant as a random effect and all other variables including their interaction terms as fixed effects in order to find out which factors determine the strength of the aha feeling. All variables were standardized into z scores for each participant level before applying the LMMs. As already mentioned, due to the compatibility between RTs and MLs, standardized MLs can be interpreted as standardized RTs (referred as RT/MLs). The coefficients of fixed effects are shown in Figure 4.3.

Suddenness and Pleasure were the two most influential factors determining the strength of Aha. In comparison, the influence of RT/ML and the interaction between Confidence and RT/ML were statistically significant but weaker than both Suddenness and Pleasure. Confidence alone was not significantly associated with the strength of Aha.

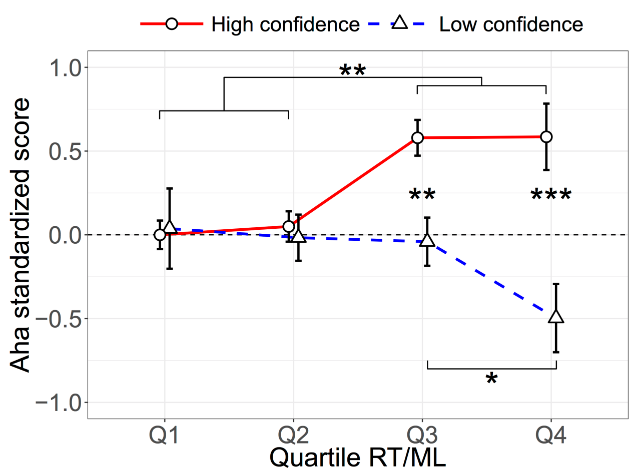

Figure 4.4 Aha z-score as functions of High/Low confidence and quartiled RT/ML. The mean z-scored aha rating as functions of subject-specific quartiles (Q1 = 0-25%ile, Q2 = 25-50%ile, Q3 = 50-75%ile, and Q4 = 75-100%ile) of response time/morphing level and split halves of confidence: High and Low confidence conditions corresponding to zConf. > 0 and zConf. < 0, respectively. Error bars show the standard error of the mean. **p* < 0.05, ***p* < 0.01, ***p < 0.001

According to the post-hoc power analysis, sample size N = 9 was sufficient to achieve power of > 0.8 in significance level = 0.05 to detect the interaction effect between confidence and RT/ML on the aha feelings. In the case of N = 10, which was actually the number we adopted in this study, the observed power was 90.2% (95% CI = [88.2, 91.8]).

To further analyze the interaction effect on Aha between Confidence and RT/ML, standardized Confidence scores were divided into two categories: High confidence ($z > 0$) and Low confidence ($z < 0$), while standardized RT/ML scores were classified into quartiles. Both coarse-graining categorizations were performed by participant-wise manner. Consequently, grand mean Aha scores were calculated and plotted as functions of binarized Confidence and quartile RT/ML (Fig. 4.4). We repeated the LMM analysis, focusing on only quartiled RT/ML as a fixed-effect factor, to High confidence and Low confidence conditions separately. In the High confidence condition, the strength of the aha experience was positively correlated with RT/ML (fixed-effect coefficient ± SEM = 0.21 ± 0.06, $t(8.79) = 3.35$, $p = 0.009$). In contrast, that was not the case in the Low confidence condition (-0.15 ± 0.11, $t(8.22) = -1.36$, $p = 0.21$). In the first LMM, z-scored confidence was treated as a continuous (or at least ordered many-valued) variable. In the second LMM, High vs. Low confidence dichotomizing was applied just for simplicity to understand the interaction effect between confidence and RT/ML on aha feelings found in the first LMM. Due to the ceiling effect, dividing into "High" and "Low" confidence may therefore be interpreted as "ceiling high confidence" and "varied low confidence." Note that categorization of RT/MLs using quartiles did not affect the results, because similar results were obtained if we used standardized RT/MLs as continuous variables as in Figure 4.3, instead of quartile RT/MLs. When comparing between High and Low confidence conditions, there were significant differences both in the 3rd and 4th quartiles (p = 0.002 and $p < 0.001$, respectively). Among the quartiles in the High confidence condition, the third and fourth were higher than the first and second (all *p*s < 0.01). Among the quartiles in the Low confidence condition, the fourth quartile was lower than the 3rd quartile ($p = 0.03$), and tended to be lower than the 2nd quartile ($p = 0.056$).

4.4 Discussion

In the present study, we found that solving a hidden figure problem may evoke intense aha feelings along with feelings of suddenness and pleasure at the time of correct answer. In addition, the interaction between the time to solve and confidence is important to engender the aha experience. Strong sense of aha is likely to occur with a longer RT and a higher confidence in the absence of any feedback, suggesting a precise metacognition about one-shot learned knowledge.

Our finding that correct solutions are more likely to induce stronger aha feelings than incorrect responses is consistent with previous works showing that insight solutions, available in an all-or-none fashion, are correct more often (Salvi *et al*., 2016) than non-insight or analytic solutions, derived by conscious and incremental steps (Webb *et al*., 2016). In our analysis, high aha ratings and high suddenness scores directly reflect the all-or-nothing nature of insight solutions. The accuracy hypothesis and the confidence hypothesis were also supported by the results of grouping into insight and non-insight solutions.

To further consider potential effects of error types and rates on our interpretation of the results related to the accuracy hypothesis, we next conducted comparisons with the previous studies. According to Salvi and colleagues (2016), who investigated the accuracy hypothesis in various insight problems, only 6.3% and 2.4% of responded answers were incorrect (i.e., errors of commission) in the compound remote associates (CRA) and anagram problems, respectively. In our case, 6.3% of "Recognized" responses in hidden figures utilizing the GCP were incorrect, the commission error rate being comparable to the cases of CRA and anagram problems (Salvi *et al*., 2016). On the other hand, while timeouts (i.e., errors of omission) were observed in 52.3% of the CRAs and 27.0% of the anagrams in the previous studies, the omission error rate of hidden figures in the current GCP setting was only 4.8%, which was fewer than those of other insight problems. Our result was not inconsistent with the accuracy hypothesis. However, it remains unclear whether accuracy hypothesis applied to hidden figures will be still valid in the case of higher incidence of omission errors than the current level. Thus, alternative approaches to induce more errors of omission in the GCP to better test the accuracy hypothesis will be promising future directions.

High suddenness scores accompanying high aha ratings suggest that the subjects were not fully aware of the ongoing cognitive process of proper problem/solution representations towards problem solving until the very moment of an aha (Sandkühler and Bhattacharya, 2008). In this respect, insight can be characterized by lack of metacognition (Metcalfe and Wiebe, 1987) about the progress of processing before the sudden realization of solution.

It is also possible to consider the suddenness score as a subjective measure of cognitive processing fluency. The fluency theory of insight (Topolinski and Reber, 2010) predicts that high processing fluency leads to high degree of aha experience with strong positive emotions. We found strong positive relationships between suddenness, pleasure and aha feelings, consistent with the theoretical predictions of the fluency theory.

According to the fluency theory, high fluency is likely to induce high confidence. In the analysis within our experimental settings, a significant correlation between confidence and aha scores was not found. The lack of correlation might be due to the ceiling effect, masking the predicted interrelation. The ceiling effect is evident from the observation that about a half (48.5%) of all the confidence ratings was given the maximum rating of 6.

The ceiling effect of confidence might be linked to higher accuracy and longer RT in the GCP paradigm, as the subjects could have adopted a "waiting strategy", by continuing to watch a hidden figure movie until the stimulus uncertainty decreased enough and confidence became high enough to answer. The mean type II AUC (= 0.90) as an index of metacognitive accuracy (Fleming *et al*., 2010; Fleming and Lau, 2014) was well above the chance level (= 0.5) and close to the perfect score (= 1.0), suggesting that high "subjective" confidence was actually accompanied by high "objective" performance. Subjects had metacognition giving a significant prediction of the correctness of the answer in the absence of any feedback.

Another possible cause of the ceiling effect might be related to the usage of Likert scales in subjective ratings. There are several manners to measure self-report assessment of aha experience and related subjective aspects. The simplest way is to use dichotomous categorization of two-alternative forced choice, i.e., yes or no (Jung-Beeman *et al*., 2004). The way of presumably the most detailed way to discriminate nuanced difference is to use continuous, visual analogue scale (VAS) or detailed step division like scales from 0 to 100 (Webb *et al.*, 2016; Danek and Wiley, 2017). There exist also studies which adopted combination of alternative measures: Danek et al. (2014a; 2014b) used continuous measurement scales of insight-affective components (e.g., pleasure, confidence, etc.), as well as binary aha (yes or no), and outlined benefits of a more sensitive scale. Webb and colleagues (2016) advocated that continuous scales might be better than dichotomising categorization because in some cases in-between strength of insight/aha responses were indeed observed. Based on their suggestion, we prevented using dichotomous binary judgment paradigms. As a third option, methods with intermediate level measurement resolution between the binary judgments and the continuous scaling are the Likert scales, for example, 5-point (Bowden and Jung-Beeman, 2003, 2007) and 6-point scale (Tik *et al.*, 2018). There continues a series of debates as to which of continuous VAS and discrete Likert scale is a better measurement method; Both of them have some advantages and also some disadvantages (for review, see Hasson and Arnetz, 2005). Usage of the Likert scales could limit the scale sensitivities to access ratings of each component of aha experience. We adopted, however, 6-point Likert scales as methods similar to Tik *et al.*, (2018) rather than VAS to reduce task demand for respondents to move slide bars needed in case of the VAS. Recently, Simms and colleagues (2019) pointed out that "no psychometric advantages were revealed for any response scales beyond 6 options, including visual analogs" (VAS). Our choice of 6-point Likert scales was also consistent with their recommendation.

In our experimental settings, all stimuli were binarised and greyscale images of known objects. Comparison with control images with no object, e.g., stimuli with just pure noise, is one of interesting further research directions. The control condition would enable a "type-1" ROC analysis, which we could not conduct here, quantifying discriminative information of signal from noise. Even in such conditions with absence of any hidden objects, people tend to find something meaningful and try to make a partial or imperfect interpretation of objects that do not actually exist in the images (Whitson and Galinsky, 2008; Liu *et al.*, 2014).

We assumed that binarised Mooney images were very difficult to interpret and original grayscale images were easy to recognize. If these assumptions were appropriate, stimulus change by constant speed between these Mooney and its grayscale counterparts would guarantee that RT or morphing level to recognize as a convenient measure of difficulty. However, median RT or morphing level as an index of difficulty diverged across hidden morphing movies. In general, there were various stimulus heterogeneity or stimulus dependency of hidden figures in gradual change paradigm (Ishikawa and Mogi, 2011) and it would be another source of difficulty. Further research is required to estimate and control the effects of stimulus dependency on the task difficulty.

In trials with short RTs (up to the median RT by subject), the mean standardized aha score was close to zero, whether confidence was high or not. Interpreting RTs as index of task difficulty, this result is consistent with Hebb's theory (1949), predicting that too easy problems cannot induce insight. The aha score did not become the lowest in trials with the shortest RT, however. The mean standardized aha level was not low enough but near zero, i.e., near the average score. One of the reasons behind this phenomenon might have been the tendency of the problem solver to be inclined to judge solution type impulsively as an insight when the RT was too short (Cranford and Moss, 2012; Salvi *et al.*, 2016).

On the other hand, in trials with RTs longer than the median by subject, the average aha z-score was higher than zero for high confidence while the score was close to or lower than zero in for low confidence. This result is in line with the fluency theory of aha (Topolinski and Reber, 2010) which advocates that unexpected fluency gives high confidence and evokes positive emotions, i.e., an aha experience.

In our analysis, the strength of the aha feeling was not determined by RT/ML or confidence alone, but by both RT/ML and confidence. An interaction between RT/ML and confidence is an important determinant of aha feeling. Within the context of "confidence hypothesis", it was found that the mean confidence was higher in insight (high aha rating) than non-insight (low aha rating) sessions. In GCP, because confidence and RT/ML was correlated, the relationship between aha and confidence might be also mediated by RT/ML. Thus, not the main effect of confidence, but the interaction effect between confidence and RT/ML on strength of aha was significant. In general, confidence levels are negatively correlated with RT/MLs (Ishikawa and Mogi, 2011), and the current result (Table 4.1) replicates the relationship; A negative relationship between confidence and RT/ML was found in the case of "by-item" analysis, or stimulus based averaging. It implies that participants tended to have, on average, lower confidence in difficult stimuli with longer/higher mean RT/MLs. In such difficult stimuli, the subjects could adopt a "waiting strategy" or viewing longer to get more information to recognize objects. Despite this general tendency, subjects can get high confidence with sudden realization even in trials with longer/higher RT/MLs. When such a special combination condition of RT/ML and confidence is met, the most intense aha feeling appears to occur.

Within the High vs. Low confidence group analyses, there are several possible interpretations. In the High confidence condition, positive relationship between aha and RT/ML indicates that (i) even in difficult stimuli requiring viewers to accumulate much more information (i.e., greater ML), participants are more likely to report a stronger aha experience if they finally get confident enough and/or (ii) people have high confidence and strong aha experience when the stimulus frames contain not enough information so that the viewer needs longer time (i.e., longer RT) to clearly recognize the image by information compilation, e.g., top-down knowledge. In the Low confidence condition, negative relationship between aha and RT/ML indicates that (iii) when it turns out that there is only insufficient information to be confident after viewing longer, people tends to have weaker aha experience or (iv) when people can recognize the image but not have confident about it, in general, they are less likely to report an aha experience. Note that the average aha z-scores were always equal to (i.e., not significantly different from) or lower than 0 in the Low confidence condition.

The results in this experiment are consistent with the incubation and restructuring theories of insight (Sandkühler and Bhattacharya, 2008), which advocate that waiting, struggling or stacked states called incubation period, mental fixation or impasse are needed before understanding problem deeply and reaching a solution to get out of the box. Long RT implies that such an incubation period, mental fixation or impasse exists before restructuring and recognition. In addition, several other factors, e.g., adapting a variety of solving strategies, may be involved in an extended RT.

As alternatives to solutions with insightful aha by intuitive and unconscious processing modes, several other solving strategies, such as trial and error, conscious, analytical, and deliberate thinking mode (Kounios *et al*., 2009; Salvi *et al*., 2016) have been proposed. When faced with difficulty and disfluency, e.g., as a consequence of prolonged RT, subjects tend to switch dominant strategy from seeking insight to non-insight, e.g., analytical thinking mode (Thompson *et al*., 2013; Alter *et al.*, 2013). This is consistent with Hebb's theory (1949), predicting that too difficult tasks do not always induce insight.

In the current GCP paradigm settings, movies of hidden figures are changing from degraded images (ML = 0%) to the blurred original images (ML = 100%) at a regular speed. In this setting, it is impossible to determine whether morphing level or RT is the more crucial metric. Interpreting RT as a measure of difficulty in our experimental settings has its limits, and should be applied with some caution. Further scrutiny is needed to clarify and dissociate effects of morphing level, ML change speed, and RT on aha feelings. Utilizing more flexible movie replay speed, for example, is one of several directions for future research. It would be interesting to investigate whether there exist optimal speeds or speed manipulation (e.g., acceleration) methods to induce an insight in GCP.

In summary, we successfully induced aha experiences accompanied by emotions such as surprise and delight in the perception of hidden figure in a laboratory setting by utilizing the GCP paradigm. It allowed us to identify the pivotal features in determining the strength of the aha. Specifically, the analysis suggests confidence and RT as metacognitive and temporal aspects contributing to the aha, respectively, with interaction between them. In conclusion, our findings provide metacognitive and temporal conditions for aha experiences, characterizing features distinct from those involved in non-aha cognitive processes.

Chapter 5:
Phenomenology of Aha in hidden figures: Affective and cognitive components (Study 3)

5.1 Introduction for Study 3

In Study3, we focused on subjective experiences in insightful moments. Some recent research has addressed multi-dimensional features of insight and revealed the phenomenology of "Aha!" experience by using multifaceted scoring method (Danek, *et al*., 2014a, 2017; Shen, *et al*., 2016, 2018; Webb, *et al*., 2016).

By modifying these new methodologies to be applied to visual one-shot learning, here we report experiments in which the subjects viewed morphing hidden figures on the screen. After each trial, the subjects were asked to provide subjective ratings in six-point scale about ten aspects: willingness to recommend (WTR), surprise, fun, suddenness, pleasure, confidence, vividness, stereoscopy, false alarm (FA, or misrecognition), tip-of-the-tongue phenomenon (TOT, a state in which only the name does not come out although it is understood) and aha experiences of hidden figures in the GCP. Specific questions of each item are described in Table 5.1.

Table 5.1 Subjective assessment questionnaire

#item	Description
1.	How suddenly did you find the perceived picture? (Suddenness/Sudden)
2.	How much are you convinced about your answer? (Confidence/Sure)
3.	How vividly did you see the answer picture? (Vividness/Vivid)
4.	How sterically did you feel about the picture? (Stereoscopicity/Sterical/3D)
5.	How interesting did you feel about the picture? (Fun)
6.	How pleased were you when you got the right answer? (Delight)
7.	How surprised did you feel at the answer? (Surprise)
8.	How long were you having a wrong figure before you got the right answer? (FA)
9.	How much did you feel the-tip-of-the-tongue state? (TOT)
10.	How much do you prefer to show this picture to your friends? (WTR)

The reasons why these subjective assessments were adopted are as follows. There are four features that typically occur at the time of the aha experience accompanying insight: (i) noticing the answer suddenly, (ii) understanding quickly and easily when it is the correct answer, (iii) bringing a positive emotion, (iv) being convinced that it be the correct answer (Topolinsiki and Reber 2010; Gick and Lockhart 1995). We selected the items that are expected to reflect them. Surprises and suddenness are related to (i), stereoscopicity and vividness which may be grounds for judging as answer are in relation to (ii), false alarm (FA) or misrecognition of distractor which inhibits correct recognition, sharing the same experiences with others (willingness to recommend, WTR), the fun/enjoyment or the pleasure of understanding something are related to (iii), while the tip-of-the-tongue (TOT) phenomenon and confidence that it was clearly understood are related to (iv).

We assumed that some of these rating scores might be related to the "Aha!" experi-ences. There are several other possible options. As the number of questions is in-creased too much, the cognitive load will be too high or the impression will fade during the answer, so we narrowed the questions down to just ten items. Also, as objective indexes, the RT was measured and the correct answer rate (accuracy) was calculated. For these subjective and objective variables, we investigated the underlying factor structure by exploratory factor analysis (EFA) to verify whether the hypothesis that insight can be best described by multidimensional perspectives (Danek, *et al*., 2014a, 2017; Shen, *et al*., 2016, 2018; Webb, *et al*., 2016) is also true in the visual one-shot learning of hidden figures.

5.2 Methods

5.2.1 Participants

Twenty-four undergraduate/graduate students (twelve females and twelve males; mean±SD age: 24±7 years old) took part in this experiment. All participants had normal or corrected-to-normal vision and all but one were right-handed. All procedures were performed with the participants' informed written consent and in accordance with the protocols approved by the Ethics Committee of National Institute of Informatics, Japan.

5.2.2 Stimuli

The process of stimuli generation used in Study 3 was almost the same as Study 1 and 2. Twenty-four grayscale pictures (300 × 300 pixels) with familiar objects (Snodgrass and Vanderwart 1980) were blurred and binarized to be unrecognizable. The resultant black and white ambiguous images are called Mooney objects (Mooney and Ferguson 1951; Mooney 1957). By morphing each Mooney object and its blurred original grayscale counterpart, intermediate images between them with various ambiguity levels were made. By connecting these series of morphing image together, we got hidden movies with 101 frames gradually changing from original blending ratio 0% to 100% in increments of 1% (Fig. 5.1).

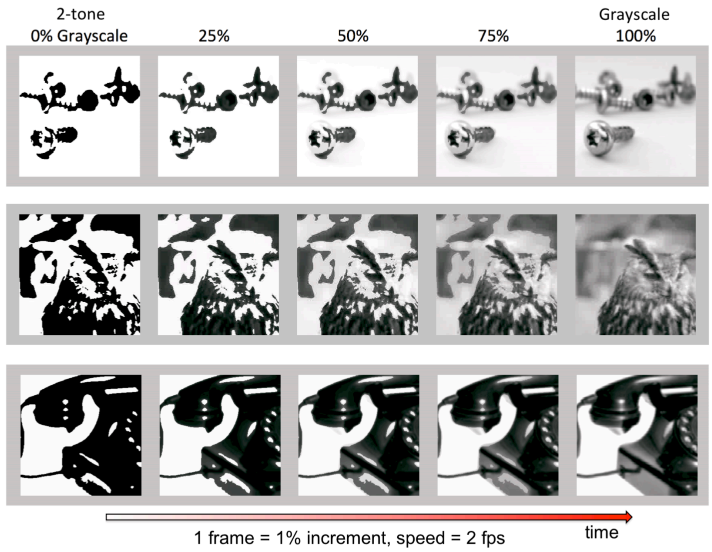

Figure 5.1 Typical example frames of morphing hidden movies (The answer: Screw, Owl, and Telephone from top to down). Reprinted by permission from Springer Nature: *Proc. ISNN2019*, Ishikawa, *et al.*, © 2019

In Study 3, the hidden movie was little longer than previous studies: Presentation time of each frame was 500 msec and thus the movie length was 50.5 sec. The reason why the movie replay speed was changed in this study was to record simultaneously eye movement patterns (data not shown). The stimuli (12.5° × 12.5°) were presented against middle gray background on the 17-inch Tobii T60 display (Tobii Technology, Stockholm, Sweden).

5.2.3 Procedure

Ten types of subjective rating (Table 5.1) in 6-point (options: 0–5) scale were asked in pseudo-random order. We did not give a linguistic description using adjectives and adverbs expressing each option. Instead, participants were asked to judge extent of feeling that it is true by the magnitude of the numerical value from 0 to 5. The order of stimulus videos was counterbalanced among the participants.

Since the total number of stimuli was small, we analyzed the data from the practice and experiment sessions without distinguishing them. The condition for judging that subjects correctly recognized hidden objects was whether or not a synonym of object name was included in the answer. Verbal reports of object name using different words across participants such as “high heels”, “heels of shoes”, or “pumps”, for example, were regarded all correct answers.

5.3 Results

On average (±SD), 91.7 ± 8.2% (22.0 ± 1.97 movies) of all the stimuli were correctly recognized. Response time was 36.0 ± 4.3 secs in correct trials and 32.3 ± 9.0 secs in incorrect trials including no response. In comparison between correct and incorrect/time out trials, all subjective ratings were higher in correct trials than in not correct trials (all *p*s $< 1.0e{-5}$, two-tailed t-tests), except for WTR ($p = 0.34$), FA ($p = 0.95$), and TOT ($p = 0.25$) (Fig. 5.2).

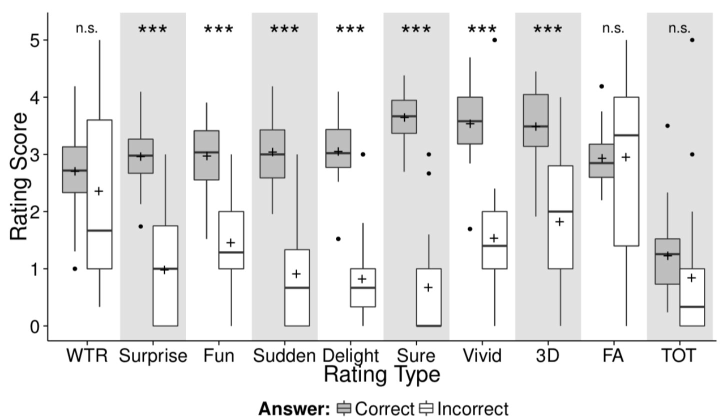

Figure 5.2 Comparison between correct and incorrect answers for each subjective assessment. Each box-whisker plot shows the maximum/minimum value (upper/lower end of the whisker) within 1.5 times the quartile range from the top/bottom of the box and outliers (•) outside of the range, mean (+), median (thick line in the box), and 1st/3rd quartiles (both ends of the box). ***$p < 1.0e\text{-}5$, n.s.: not significant. Reprinted by permission from Springer Nature: *Proc. ISNN2019*, Ishikawa, *et al.*, © 2019

Because the number of error trials were not enough for further analysis, henceforth, only data in correct trials were analyzed. We performed correlation analysis between the 10-item subjective ratings and two task performance measures, i.e., RT and accuracy (correct rate, abbreviated as Correct in Figs and Tables), calculated for each stimulus.

There were many combinations showing positive correlations among them, while negative correlations were observed only in four combinations: (i) RT and confidence, (ii) RT and 3D, (iii) RT and accuracy, and (iv) confidence and TOT. Only one variable showed a positive correlation with RT was FA (Table 5.2).

Table 5.2 Correlation analysis between subjective evaluation and performance (Pearson correlation coefficients)

	WTR	Surprise	Fun	Sudden	Delight	Sure	Vivid	3D	Correct	FA	RT
WTR											
Surprise	.83♭										
Fun	.88♭	.82♭									
Sudden	.84♭	.84♭	.91♭								
Delight	.81♭	.73♭	.91♭	.88♭							
Sure	.52♮	.44♯	.65♭	.66♭	.82♭						
Vivid	.59♮	.59♮	.74♭	.77♭	.80♭	.84♭					
3D	.49♯	.47♯	.68♭	.68♭	.66♭	.72♭	.84♭				
Correct	.24	.22	.38	.45♯	.39	.49♯	.48♯	.49♯			
FA	.47♯	.74♭	.38	.46♯	.24	-.12	.14	.01	-.18		
RT	.11	.26	-.05	-.03	-.26	-.56♯	-.35	-.42♯	-.48♯	.74♭	
TOT	-.13	-.12	-.19	-.11	-.37	-.53♮	-.12	-.09	-.16	.15	.30

♯ $p < 0.05$, ♮ $p < 0.01$, ♭ $p < 0.001$. Significant values highlighted by shading.

Correct: correct rate, RT: response time, the other abbreviations: cf. Table 4.1

Reprinted by permission from Springer Nature: *Proc. ISNN2019*, Ishikawa, *et al.*, © 2019

In order to reveal latent structures behind observed variables, exploratory factor analysis (EFA) was carried out. For the first step of EFA, it was necessary to infer the number of factors.

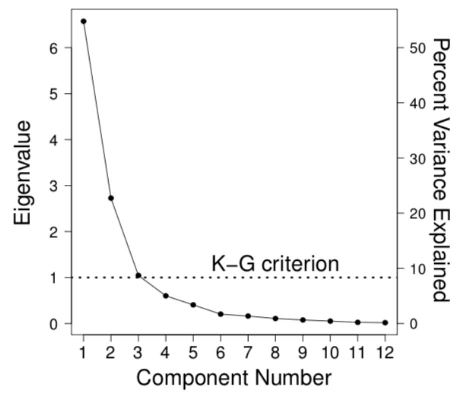

Figure 5.3 Scree plot to estimate factor number. Three-factor structure is plausible. Reprinted by permission from Springer Nature: *Proc. ISNN2019*, Ishikawa, *et al.*, © 2019

According to the Scree plot (Fig. 5.3) in which the eigenvalues were arranged in order of magnitude, variance of the first factor was accounted for more than twice of the variance of the other factors. The Scree test to estimate factor numbers from location of "elbow" in the graph shape suggested that there existed an underling three factor structure. There is another rule of thumb, called the Kaiser–Guttman (KG) criterion, proposing that the number of eigenvalues equal to or larger than 1.0 is regarded as the factor number. In light of this KG criterion, the estimated number of factors was 3. Therefore it was reasonable to conclude that a three-factor model was most likely.

The factor loadings (ML1, ML2, ML3, corresponding to the first, second, and third factors, respectively) and the commonality (h^2) were estimated (Table 5.3) through maximum likelihood method with the Promax rotation.

Table 5.3 Factor loadings and commonalities in three-factor structure

	ML1	ML2	ML3	h^2
WTR	0.84	0.33	0.00	0.79
Surprise	0.80	0.56	-0.06	0.92
Fun	0.94	0.18	-0.01	0.89
Sudden	0.97	0.20	0.08	0.93
Delight	0.91	0.01	-0.15	0.92
Sure	0.73	-0.36	-0.27	0.91
Vivid	0.90	-0.21	0.15	0.82
3D	0.80	-0.30	0.18	0.70
Correct	0.47	-0.35	0.04	0.35
FA	0.34	0.90	0.01	0.89
RT	-0.18	0.87	0.04	0.83
TOT	0.01	0.04	0.99	1.00

Abbreviations shown in Table 5.1, except for Correct: correct rate, RT: response time.

Next, to investigate whether there was a substructure in the biggest factor, nine variables strongly related to the first factor were selected and further analyzed. Results of the Scree test and the KG criterion (Fig. 5.4) consistently suggested that there might be two subfactors (ml1 and ml2) in the original main factor (Table 5.4).

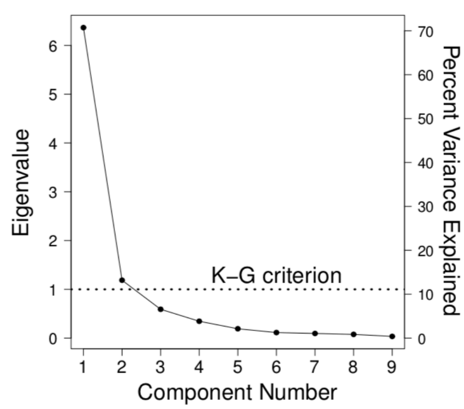

Figure 5.4 Scree plot to estimate subfactor number. Two-factor structure is plausible.

Table 5.4 Two-subfactor structure underlying the first factor (ML1)

	ml1	ml2	h^2
WTR	0.99	-0.08	0.87
Surprise	0.96	-0.11	0.79
Fun	0.81	0.21	0.94
Sudden	0.75	0.27	0.90
Delight	0.58	0.45	0.90
Sure	-0.05	0.94	0.83
Vivid	0.10	0.86	0.87
3D	0.03	0.83	0.72
Correct	-0.09	0.60	0.30

Reprinted by permission from Springer Nature: *Proc. ISNN2019*, Ishikawa, *et al.*, © 2019

To facilitate visually understanding the results of factor analyses, we plotted the factor loadings of the first and the second factor in Figure 5.5.

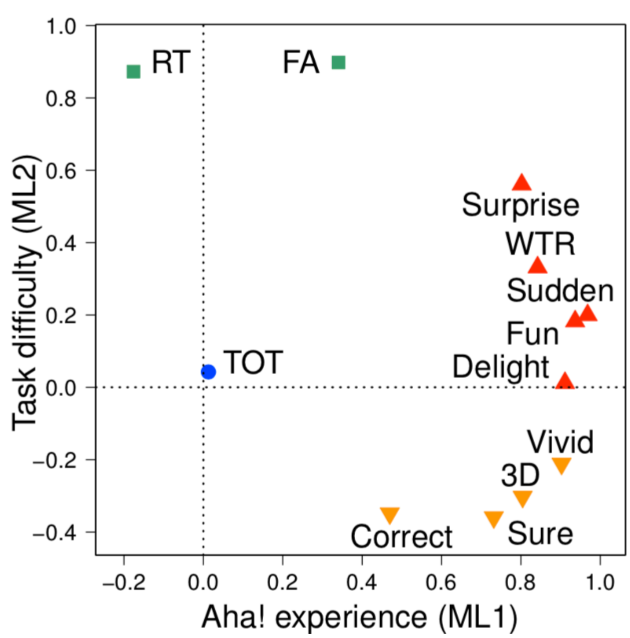

Figure 5.5 Factor loadings of observed variables placed on 1st–2nd factor plane. Shape/color coded by subfactors. Correct: correct rate, RT: response time, the other abbreviations and its descriptions were explained in Table 5.1. Reprinted by permission from Springer Nature: *Proc. ISNN2019*, Ishikawa, *et al.*, © 2019

Variables having a strong connection to the first factor ML1 were depicted by a triangle (▲ or ▼). Other variables having a strong influence on the second factor ML2 were depicted by a square (■). Those related to the third factor ML3 (represented by the axis orthogonal to the plane on the figure) were shown by circles (●).The subfactor ml1 (▲) had a positive correlation with the second factor ML2, while subfactor ml2 (▼) was negatively correlated with the second factor ML2.

5.4 Discussion

In seven out of ten items in the subjective ratings, rated scores were significantly higher in correct answer trials than in incorrect ones, suggesting that the participants had stronger feelings when they reached the correct answers: they were surprised and convinced to find suddenly a vivid 3D object in the stimulus and pleased to have such a fun experience. There was, however, no difference in the WTR, FA (e.g., mental fixation) and TOT phenomenon ratings between correct and incorrect conditions.

The WTR judgment could be regarded as an indicator of word-of-mouth. In marketing research, it is known that there is a U-shaped relationship between product satisfaction level and frequencies of word-of-mouth generation. When the product is very satisfac-tory or otherwise not very satisfactory for customers, the word-of-mouth reactions are most likely to be induced (Anderson 1998). If the correct answer gives a sense of satisfaction and, on the other hand, incor-rect/unsolved (or at least not fully achieved disambiguation) case provides a feeling of dissatisfaction, it would be a natural consequence that the urge to spread word-of-mouth or willingness to recommend becomes high in either case.

In the debriefing after experiment, some of the participants wanted to know the answers and the results of the problems and they also wanted to know whether others could solve them. According to the cognitive dissonance theory (Festinger 1957), in the case when the participants cannot solve the problems, they tend to rationalize that it is not a lack of ability of themselves but because these problems are so much difficult that nobody can solve them.

The factors obtained by EFA can be interpreted as follows. Variable group of the major factor (ML1) with the highest factor loading (mainly appearing on the right-hand side in Fig. 5.5) can be interpreted as an axis of "Aha!" experience, because this axis has relevant features characterizing the "Aha!" experience, such as feelings of suddenness, confidence and positive emotions, with other several insight problem domains (Topolinski and Reber, 2010; Gick and Lockhart, 1995). On the other hand, variables constituting the second factor (ML2) can be interpreted as an axis of Task difficulty, since this direction has positive correlations with RT and FA, and negative correlations with confidence and accuracy. The first "Aha!" experience axis is a factor related to the state of the subjective experience that occurs at the moment, and the second Task difficulty axis is a factor related to the state until the answer is known. The third small factor (ML3) consisting of the TOT phenomenon is rather independent from the other factors. Moreover, as a substructure of the first factor, there were two sub-factors. The first sub-factor (ml1) is considered to reflect the more affective aspect of "Aha!" experiences, while the second sub-factor (ml2) reflects more objective judgment on perception and (re)cognition, which is consistent with Shen, *et al*., (2016, 2018).

In summary, we found two salient factors describing both subjective and objective features of visual one-shot learning in morphed hidden figures, which were interpreted as "Aha!" experience and Task difficulty. Furthermore, the "Aha!" experience consists of two sub components: Affective and Cognitive components of insight. The fact that WTR is a strong indicator of the “Aha!” experience, particularly its Affective components, is, to our best knowledge, a novel finding. The results suggested that insight can be characterized by multidimensional factors in the case of visual one-shot learning, as in common with other problem domains and modalities. In conclusion, we characterized the phenomenology of “Aha!” experience in the visual one-shot learning for further creative journey.

Chapter 6:
General Discussion

Studying various modes of visual perception provides a salient tool for clarifying certain aspects of awareness and consciousness. Among several choreographies of visual systems providing visual insights, especially sudden realization of object representation concealed in hidden figures sometimes show "once and for all" nature of one-shot learning. In order to establish a method allowing us to experimentally induce visual insight, we developed a morphing Gradual Change Paradigm in hidden figures and paved a new avenue of insight research. By utilizing the GCP, we created a lot of hidden figures systematically and examined a pivotal role of metacognition, especially confidence, in one-shot learning on hidden figure recognition in the first study (Chapter 3). The abrupt realization of the hidden figure in the GCP provides a robust experimental tool to investigate certain aspects of conscious visual perception, especially visual one-shot learning in its systematic and temporal richness.

The second study (Chapter 4) revealed that an "aha" experience of hidden figures induced in the GCP protocol can be characterized by interaction effect between confidence and recognition time along with strong positive emotion, i.e., pleasure and unexpected surprise, i.e., feeling of suddenness. Furthermore, the third study (Chapter 5) scrutinized multidimensional subjective aspects to reveal the phenomenology of aha experiences in hidden figures by applying the GCP with more diverging subjective assessments.

Before our studies, except for a few heuristics (Mogi *et al*. 2006), little was understood about how to create “good” hidden figures that can elicit strong “Aha!” feelings. Defining the "goodness" as an insight problem *per se* probably is an insight problem. As further issues related to the “goodness” problem, there remains several attractive questions: Are there any image features characterizing the "good" hidden figures? What factors can define the individual differences in aha-proneness? Is it possible to enhance the aha-proneness? If possible, how? Last but not least, the most important practical question to be examined, is what (if any) is *optimal* control (e.g., speed or acceleration manipulation of hidden movie replay) to induce an insight in the GCP?

In this thesis, we mainly focused on subjective aspects of insight. For further works, to search for precursory change of behavioral/physiological signals, such as eye movement, pupil dilation, and/or blink patterns before conscious awareness of aha experiences in hidden figures, is another promising direction.

In conclusion, we established a brand-new paradigm called the Gradual Change Paradigm applicable to conduct insight research using hidden figures. Thanks to that, one-shot learning satisfying required accuracy and aha experiences in a certain time constraint can be induced in experimental settings. Our findings through the GCP experiments provided affective, metacognitive and temporal conditions for aha experiences of hidden figures in Gradual Change Paradigm, characterizing features distinct from those involved in non-aha cognitive processes.

Bibliography

Ahissar M, Hochstein S. (1997) Task difficulty and the specificity of perceptual learning. Nature 387:401–406

Allen M, Glen JC, Müllensiefen D, Schwarzkopf DS, Fardo F, Frank D, Callaghan MF, Rees G. (2017) Metacognitive ability correlates with hippocampal and prefrontal microstructure. Neuroimage 149:415-423. doi:10.1016/j.neuroimage.2017.02.008

Allen WL, Cuthill IC, Scott-Samuel NE, Baddeley R (2011) Why the leopard got its spots: relating pattern development to ecology in felids. Proc Biol Sci 278(1710):1373–1380

Alter AL, Oppenheimer DM, Epley N. (2013) Disfluency prompts analytic thinking—but not always greater accuracy: response to Thompson *et al*. (2013). Cognition 128(2):252-5. doi: 10.1016/j.cognition.2013.01.006

Anderson EW (1998) Customer satisfaction and word of mouth. J service research 1(1): 5-17.

Auble, P. M., Franks, J. J., Soraci, S. A. (1979) Effort toward comprehension: Elaboration or “aha!”? Memory & Cognition, 7, 426–434.

Aziz-Zadeh, L., Kaplan, J. T., Iacoboni, M. (2009) “Aha!”: The neural correlates of verbal insight solutions. Hum. Brain Mapp., 30(3), 908–916.

Bland JM, Altman DG (1998) Survival probabilities (the Kaplan- Meier method). BMJ 317(7172):1572

Bowden EM, Jung-Beeman M, Fleck J, Kounios J (2005) New approaches to demystifying insight. Trends Cogn Sci 9(7):322–328

Bowden, E. M. (1997) The effect of reportable and unreportable hints on anagram solution and the aha! experience. Conscious. Cogn., 6(4), 545–573.

Bowden EM, Jung-Beeman M (2003) Aha! Insight experience correlates with solution activation in the right hemisphere. Psychon Bull Rev 10: 730–737. doi: 10.3758/BF03196539

Bowden EM, Jung-Beeman M (2007) Methods for investigating the neural components of insight. Methods 42(1):87–99. doi: 10.1016/j.ymeth.2006.11.007

Bowers K, Regehr G, Balthazard C, Parker K (1990) Intuition in the context of discovery. Cogn Psychol 22(1):72–110

Brainard DH (1997) The Psychophysics Toolbox. Spat Vis 10(4):433-6. doi: 10.1163/156856897X00357

Brysbaert M, Stevens M (2018) Power Analysis and Effect Size in Mixed Effects Models: A Tutorial. Journal of Cognition 1(1) 9: 1–20. doi: 10.5334/joc.10

Bühler, K. L. (1907) Tatsachen und Probleme zu einer Psychologie der Denkvorgänge. I: Über Gedanken. Archiv für die gesamte Psychologie, 9, 297–365.

Castelhano J, Rebola J, Leitão B, Rodriguez E, Castelo-Branco M (2013) To perceive or not perceive: the role of gamma-band activity in signaling object percepts. PLoS One 8(6):e66363. doi: 10.1371/journal.pone.0066363

Chi RP, Snyder AW (2011) Facilitate insight by non-invasive brain stimulation. PLoS One 6(2):e16655

Cranford EA, Moss J (2012) Is Insight Always the Same? A Protocol Analysis of Insight in Compound Remote Associate Problems. The Journal of Problem Solving 4(2): 8. doi: 10.7771/1932-353 6246.1129

Dallenbach KM (1951) A picture puzzle with a new principle of concealment. Am J Psychol 64:431-433. doi: 10.2307/1419008

Danek AH, Fraps T, von Müller A, Grothe B, Ollinger M (2013) Aha! experiences leave a mark: facilitated recall of insight solutions. Psychol Res 77(5):659-69. doi: 10.1007/s00426-012-0454-8

Danek AH, Fraps T, von Müller A, Grothe B, Öllinger M (2014a) It's a kind of magic-what self-reports can reveal about the phenomenology of insight problem solving. Front Psychol 5:1408. doi: 10.3389/fpsyg.2014.01408

Danek AH, Fraps T, von Müller A, Grothe B, Öllinger M (2014b) Working Wonders? Investigating insight with magic tricks. Cognition 130(2): 174–185. doi: 10.1016/j.cognition.2013.11.003

Danek AH, Salvi C (2018) Moment of Truth: Why Aha! Experiences are Correct. The Journal of Creative Behavior [Epub ahead of print]. doi: 10.1002/jocb.380

Danek AH, Wiley J (2017). What about False Insights? Deconstructing the Aha! Experience along Its Multiple Dimensions for Correct and Incorrect Solutions Separately. Front Psychol 7:2077. doi: 10.3389/fpsyg.2016.02077

Davenport JL, Potter MC (2004) Scene consistency in object and background perception. Psychol Sci 15(8):559–564

Dolan RJ, Fink GR, Rolls E, Booth M, Holmes A, Frackowiak RS, Friston KJ (1997) How the brain learns to see objects and faces in an impoverished context. Nature 389:596-599. doi: 10.1038/39309

Dudai Y, Morris RG (2013) Memorable trends. Neuron 80(3):742-50. doi: 10.1016/j.neuron.2013.09.039

Ekstrom RB, French JW, Harman HH, Dermen D (1976) Manual for kit of factor-referenced cognitive tests. Princeton Educational Testing Service, New Jersey

Festinger L. (1957) A theory of cognitive dissonance, Stanford university press.

Fleming SM, Lau HC (2014) How to measure metacognition. Front Hum Neurosci 8: 443. doi: 10.3389/fnhum.2014.00443

Fleming SM, Weil RS, Nagy Z, Dolan RJ, Rees G (2010) Relating introspective accuracy to individual differences in brain structure. Science 329:1541-3. doi: 10.1126/science.1191883

Folke T, Jacobsen C, Fleming SM, De Martino B (2016) Explicit representation of confidence informs future value-based decisions. Nature Human Behaviour 1: 0002. doi: 10.1038/s41562-016-0002

Gick ML, Lockhart RS (1995) Cognitive and affective components of insight. In: Sternberg RJ, Davidson JE (eds) The nature of insight. MIT Press, Cambridge, pp 197-228

Gigerenzer, G. (2007) Gut Feelings: The Intelligence of the Unconscious, Viking Press, New York.

Giovannelli F, Silingardi D, Borgheresi A, Feurra M, Amati G, Pizzorusso T, Viggiano MP, Zaccara G, Berardi N, Cincotta M (2010) Involvement of the parietal cortex in perceptual learning (Eureka effect): an interference approach using rTMS. Neuropsychologia 48(6):1807-12. doi: 10.1016/j.neuropsychologia.2010.02.031

Green P, MacLeod CJ (2016) SIMR: An R package for power analysis of generalized linear mixed models by simulation. Methods in Ecology and Evolution 7(4): 493–498, doi: 10.1111/2041-210X.12504

Gregory RL (1970) The intelligent eye. Weidenfeld & Nicolson, London

Hasson D, Arnetz BB (2005) Validation and findings comparing VAS vs. Likert scales for psychosocial measurements. International Electronic Journal of Health Education 8:178–192.

Heath C, Heath D (2007) Made to stick: Why some ideas survive and others die. New York, NY: Random House

Hebb DO (1949) The organization of behavior: A neuropsychological theory. Wiley, New York

Hedne MR, Norman E, Metcalfe J (2016) Intuitive Feelings of Warmth and Confidence in Insight and Noninsight Problem Solving of Magic Tricks. Front Psychol 7:1314. doi: 10.3389/fpsyg.2016.01314

Hegdé J, Kersten D (2010) A link between visual disambiguation and visual memory. J Neurosci 30(45):15124-33. doi: 10.1523/JNEUROSCI.4415-09.2010

Horvitz, L. A. (2002) Eureka!: Scientific Breakthroughs that Changed the World, John Wiley & Sons, Inc., New York.

Hsieh PJ, Vul E, Kanwisher N (2010) Recognition alters the spatial pattern of FMRI activation in early retinotopic cortex. J Neurophysiol 103(3):1501–1507

Imamoglu F, Kahnt T, Koch C, Haynes JD (2012) Changes in functional connectivity support conscious object recognition. Neuroimage 63(4):1909-17. doi: 10.1016/j.neuroimage.2012.07.056

Ishikawa T, Mogi K (2011) Visual one-shot learning as an 'anti-camouflage device': a novel morphing paradigm. Cogn Neurodyn 5(3):231-9. doi: 10.1007/s11571-011-9171-z

Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R. *et al*., (2004) Neural activity when people solve verbal problems with insight. PLoS Biology, 2(4), e97.

Kekulé, A. (1890) Benzolfest: Rede, Ber. Dtsch. Chem. Ges., 23, 1302–1311. Köhler, W. (1917) Intelligenzenprüfungen an Anthro-poiden [The Mentality of Apes], Winter, E., Trans. (1925) Harcourt, Brace, New York.

Kizilirmak JM, da Silva JGG, Imamoglu F, Richardson-Klavehn A (2016) Generation and the subjective feeling of "aha!" are independently related to learning from insight. Psychol Res 80(6):1059-1074. doi: 10.1007/s00426-015-0697-2

Kounios J, Beeman M (2014) The cognitive neuroscience of insight. Annual review of psychology 65:71-93. doi: 10.1146/annurev-psych-010213-115154

Kounios J, Beeman M (2009) The Aha! Moment the cognitive neuroscience of insight. Curr Dir Psychol Sci 18(4):210–216. doi: 10.1111/j.1467-8721.2009.01638.x

Laukkonen RE, Tangen JM (2018) How to Detect Insight Moments in Problem Solving Experiments. Front Psychol 9:282. doi: 10.3389/fpsyg.2018.00282

Liu J, Li J, Feng L, Li L, Tian J, Lee K (2014) Seeing Jesus in toast: neural and behavioral correlates of face pareidolia. Cortex 53:60¬–77. doi: 10.1016/j.cortex.2014.01.013

Ludmer R, Dudai Y, Rubin N (2011) Uncovering camouflage: amygdala activation predicts long-term memory of induced perceptual insight. Neuron 69(5):1002-14. doi: 10.1016/j.neuron.2011.02.013

Luo, J., Niki, K. (2003) Function of hippocampus in “insight” of problem solving. Hippocampus, 13(3), 316–323.

Metcalfe J (1986) Premonitions of Insight Predict Impending Error. Journal of Experimental Psychology Learning Memory and Cognition 12(4):623-634. doi: 10.1037/0278-7393.12.4.623

Metcalfe J, Wiebe D (1987) Intuition in insight and noninsight problem solving. Memory & Cognition 15(3): 238–246. doi:10.3758/BF03197722

Mogi K, Sekine T, Tamori Y (2005) Slow and fast processes in visual ‘one-shot’ learning. Perception 34 ECVP Abstract Supplement 15–16

Mogi K, Tamori Y (2006) Making good hidden figures. Perception 35 ECVP Abstract Supplement 200–201

Mogi K, Tamori Y (2007) Temporal characteristics of visual one-shot learning. Perception 36 ECVP Abstract Supplement 51-52

Mogi, K., Sekine, T., Tamori, Y. (2005) Slow and fast processes in visual ‘one-shot’ learning. Perception 34 ECVP Abstract Supplement 15–16.

Mooney CM (1957) Age in the development of closure ability in children. Can J Psychol 11(4):219-26. doi: 10.1037/h0083717

Mooney CM, Ferguson GA (1951) A new closure test. Can J Psychol 5(3):129-133. doi: 10.1037/h0083540

Morewedge, C. K., Kahneman, D. (2010) Associative processes in intuitive judgment. Trends. Cogn. Sci., 14(10), 435–440.

Murata T, Hamada T, Shimokawa T, Tanifuji M, Yanagida T (2014) Stochastic process underlying emergent recognition of visual objects hidden in degraded images. PLoS One 9(12):e115658. doi: 10.1371/journal.pone.0115658

Nieder A (2002) Seeing more than meets the eye: processing of illusory contours in animals. J Comp Physiol A Neuroethol Sens Neural Behav Physiol 188(4):249–260

Oppenheimer DM (2008) The secret life of fluency. Trends Cogn Sci 12(6):237-41. doi: 10.1016/j.tics.2008.02.014

Pelli DG (1997) The VideoToolbox software for visual psychophysics: transforming numbers into movies. Spat Vis. 10(4):437-42. doi: 10.1163/156856897X00366

Rahnev D, Nee DE, Riddle J, Larson AS, D'Esposito M (2016) Causal evidence for frontal cortex organization for perceptual decision making. Proc Natl Acad Sci USA 113(21):6059-64. doi: 10.1073/pnas.1522551113

Ramachandran VS (1987) Visual perception of surfaces: a biological theory. In: Petry S, Meyer GE (eds) The perception of illusory contours. Springer, Berlin Heidelberg New York, pp 93–108

Ramachandran VS (1995) 2-D or not 2-D?—that is the question. In: Gregory R, Harris J, Heard P, Rose D (eds) The artful eye. Oxford University Press, Oxford New York, pp 249–267

Rodriguez E, George N, Lachaux JP, Martinerie J, Renault B, Varela FJ (1999) Perception's shadow: long-distance synchronization of human brain activity. Nature 397:430–433

Rubin, N., Ludmer, K., Dudai, Y. (2006) Changes in stimulus appearance mediating abrupt improvements in perceptual tasks. Perception, 35, ECVP Abst. Suppl., 113–114.

Rutishauser U, Ross IB, Mamelak AN, Schuman EM (2010) Human memory strength is predicted by theta-frequency phase-locking of single neurons. Nature 464:903–907

Salvi C, Bricolo E, Kounios J, Bowden E, Beeman M (2016) Insight solutions are correct more often than analytic solutions. Think Reason 22(4):443-460. doi: 10.1080/13546783.2016.1141798

Sandkühler S, Bhattacharya J (2008) Deconstructing insight: EEG correlates of insightful problem solving. PLoS One 3(1):e1459. doi: 10.1371/journal.pone.0001459

Shen W, Yuan Y, Liu C, Luo J (2016) In search of the 'Aha!' experience: Elucidating the emotionality of insight problem-solving. Br J Psychol 107(2):281-98. doi: 10.1111/bjop.12142

Shen, W., Tong, Y., Li, F., Yuan, Y., Hommel, B., Liu, C., & Luo, J. (2018). Tracking the neurodynamics of insight: a meta-analysis of neuroimaging studies. Biological psychology, 138: 189-198. doi: 10.1016/j.biopsycho.2018.08.018

Simms, L. J., Zelazny, K., Williams, T. F., Bernstein, L. (2019) Does the number of response options matter? Psychometric perspectives using personality questionnaire data. Psychological Assessment. [Epub ahead of print] doi: 10.1037/pas0000648

Singer W (2009) Distributed processing and temporal codes in neuronal networks. Cogn Neurodyn 3(3):189–196

Snodgrass JG, Vanderwart M (1980) A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. J Exp Psychol Hum Learn 6(2):174-215. doi: 10.1037/0278-7393.6.2.174

Street RF (1931) A gestalt completion test. Contributions to education 481. Columbia University Teachers College, New York

Stukeley, W. (1752) Memoirs of Sir Isaac Newton's Life, The Royal Society Library, London.

Thompson VA, Turner JA, Pennycook G, Ball LJ, Brack H, Ophir Y, Ackerman R (2013) The role of answer fluency and perceptual fluency as metacognitive cues for initiating analytic thinking. Cognition 128(2):237-51. doi: 10.1016/j.cognition.2012.09.012

Tik M, Sladky R, Luft CDB, Willinger D, Hoffmann A, Banissy MJ, Bhattacharya J, Windischberger C (2018) Ultra-high-field fMRI insights on insight: Neural correlates of the Aha!-moment. Hum Brain Mapp 39(8):3241–3252. doi: 10.1002/hbm.24073

Topolinski S, Reber R (2010) Gaining Insight Into the "Aha" Experience. Current Directions in Psychological Science 19(6):402-405. doi: 10.1177/0963721410388803

Tovee MJ, Rolls ET, Ramachandran VS (1996) Rapid visual learning in neurones of the primate temporal visual cortex. Neuroreport 7(15–17):2757–2760

Vitruvius MP. (ca. 27 B.C.) De Architectura, Liber IX, praefatio 10.

Volz KG, von Cramon DY. (2006) What neuroscience can tell about intuitive processes in the context of perceptual discovery. J. Cogn. Neurosci., 18(12), 2077–2087.

Webb ME, Little DR, Cropper SJ (2016) Insight Is Not in the Problem: Investigating Insight in Problem Solving across Task Types. Front Psychol 7:1424. doi: 10.3389/fpsyg.2016.01424

Webb ME, Little DR, Cropper SJ (2018) Once more with feeling: Normative data for the aha experience in insight and non-insight problems. Behavior Research Methods 50(5):2035–2056. doi: 10.3758/s13428-017-0972-9

Webb ME, Cropper SJ, Little DR (2019) "Aha!" is stronger when preceded by a "huh?": Presentation of a solution affects ratings of aha experience conditional on accuracy. Thinking & Reasoning [Epub ahead of print]. doi: 10.1080/13546783.2018.1523807

Weisberg RW (2015) Toward an integrated theory of insight in problem solving. Thinking & Reasoning 21(1):5-39. doi: 10.1080/13546783.2014.886625

Werner G (2009) Consciousness related neural events viewed as brain state space transitions. Cogn Neurodyn 3(1):83–95

Whitson JA, Galinsky AD (2008) Lacking control increases illusory pattern perception. Science 322:115–7. doi: 10.1126/science.1159845

Publications

Peer-reviewed Papers

1. Ishikawa, T. and Mogi, K. (2011)*** "Visual one-shot learning as an 'anti-camouflage device': a novel morphing paradigm." *Cognitive Neurodynamics* 5(3): 231–239.

2. Toshima, M., Ishikawa, T. and Mogi, K. (2011) "Spaces Enhance Word Segmentation and Comprehension in Tacit Reading." *Advances in Neural Networks – ISNN 2011*, *Lecture Notes in Computer Science* 6675, 76–82.

3. Ishikawa, T., Toshima, M., Garkavijs, V., Mogi, K. and Kando, N. (2013) "Fundamental Discussion on Serendipitous Discovery During Visual Information Seeking." [in Japanese] In: *Proceedings of the Fifth Information Access Symposium*, Dec 6, 2013, Tokyo, Japan, pp.1–8, Information Processing Society of Japan.

4. Garkavijs, V., Okamoto, R., Ishikawa, T., Toshima, M., Kando, N. (2014) "GLASE-IRUKA: Gaze Feedback Improves Satisfaction in Exploratory Image Search." In: *Proceedings of the 23rd international conference on World Wide Web (WWW2014)*, April 7-11, 2014, Seoul, Korea, pp.273–274.

5. Ishikawa, T., Toshima, M., and Mogi, K. (2019a)*** "How and when? Metacognition and solution timing characterize an “aha” experience of object recognition in hidden figures." *Frontiers in Psychology: Consciousness Research* [in press]

6. Ishikawa, T., Toshima, M., and Mogi, K. (2019b)*** "Phenomenology of Visual One-shot Learning: Affective and Cognitive Components of Insight in Morphed Gradual Change Hidden Figures." In: *Proceedings of the 16th International Symposium on Neural Network (ISNN2019), pp.1–8.* [in press]

7. Kawakami, E., Tabata, J., Yanaihara, N., Ishikawa, T., Koseki, K., Iida, Y., Saito, M., Komazaki, H., Shapiro, J., Goto, C., Akiyama, Y., Saito, R., Takano, H., Yamada, K., and Okamoto, A. (2019) "Application of artificial intelligence for preoperative diagnostic and prognostic prediction in epithelial ovarian cancer based on blood biomarkers." *Clinical Cancer Research* [in press]

Papers and Book chapters (non-reviewed)

- Ishikawa, T. and Mogi, K. (2010) "Creativity and Visual One-shot Learning." *CARLS Series of Advanced Study of Logic and Sensibility Vol.4 2010*, Chap. 13, 113–119.
- Toshima, M., Ishikawa, T., and Kando, N. (2013a) "The Way to the Knowledge Acquisition: How the University Students of the Digital Native Generation Get Themselves into Information Searching Behavior on the Web." [in Japanese] *Journal of Japan Society of Information and Knowledge*, 23(2), 286–291.
- Toshima, M., Ishikawa, T., and Kando, N. (2013b) "How to Get University Students Involved in Information Searching and Community Education System." [in Japanese] In: *Proceedings of the 27th Annual Conference of the Japanese Society for Artificial Intelligence*, June 4-7, 2013, Toyama, Japan, 1B3-6, pp.1–4.
- Ishikawa, T., Toshima, M., Garkavijs, V., Okamoto, R., Mogi, K., and Kando, N. (2014) "Delight or Chagrin? Problem Solving May Elicit Both Positive and Negative

Emotions." [in Japanese] In: *Proceedings of the 156th meeting of Information Processing Society of Japan Special Interest Group on Human-Computer Interaction*, Jan 15–16, 2014, Gero Hot Spring, Japan, IPSJ Technical Report, 2014-HCI-156, Vol.5, pp.1–6.

- Ishikawa, T., Toshima, M., Garkavijs, V., Okamoto, R., Kando, N., and Mogi, K. (2014) "Changes of Pupil Size Precede Aha! Experience in Hidden Figure Perception." [in Japanese] In: *Proceedings of the Workshop on Analysis and Modelling of Noninvasive Biosignals and Related Topics, Institute of Statistical Mathematics*, December 6–7, 2013, Tokyo, Japan, ISM Collaborative Research Report, Vol.310, pp.59–68.

***Study 1, 2, and 3 in this thesis correspond to Ishikawa and Mogi (2011); Ishikawa, Toshima, and Mogi (2019a); and Ishikawa, Toshima, and Mogi (2019b), respectively.