Four Questions on Visual Self-recognition

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Development, Evolution, Function, and Mechanisms

By

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To my wonderful family and close friends, without whom I simply could not have made this journey. May the humble contents within somehow contribute to an increased understanding and benefit for those who need it.

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PREFACE

This book is a regurgitation of my PhD thesis on visual self-recognition, with some chapters already appearing in print. Cambridge Scholars Press simply provided me with an opportunity not to be missed: interested readers can now digest the complete package–rather than independent publications-as I had originally intended.

Writing this book resulted in many experiences both good and bad. I now have an inner strength that will be difficult to extinguish, and this is due to several people. I am eternally indebted to my family and my close friends. A few warrant specific mention. Kristy Dennerley–I simply could not have completed this in *any way* without your assistance, and I wonder whether I will ever really know how much it cost you; this book is as much yours as it is mine. Dr. Emma Collier-Baker–your insight and passion for ethical topics that we both share rekindled my motivation when needed. To my little canine brother from another mother-Elvis-thanks for making me become more grounded and considerate of others at a time when pressure was mounting.

This book is not a solo effort. During the course of my PhD I was blessed with a fantastic advisory team, all of whom are not only the best at what they do, but are exceptional people.[1] Professor Thomas Suddendorf–you are "the man". Your continual interest and discipline have forged me into the thinker I am today and I can never repay all the hard work you contributed in overseeing the contents of this book. You have provided me with 'big picture' perspectives I would have otherwise remained ignorant of and these will continue to influence my view involving both work and life. Professor Jason Mattingley and Associate Professor Ross Cunnington-you have both provided me with extensive technical and practical expertise that will serve me well for the remainder of my professional career. Your humility in our interactions is something I hope to replicate with my students. A few other people's assistance also warrant acknowledgement. Mr. Paul Jackson designed the computer program to run my experiments (Chapters 2 to 4). The Australian Twin Registry provided me with assistance in recruiting twins (Chapter 2). Mr. Ian Firth, Ms. Mary Verney, Mr. Rennie Fletcher and anonymous reviewers provided

[1] For full details please see 'List of Contributors' at the end of this book.

constructive comments for Chapter 3. Professor Ottmar Lipp instructed me how to use galvanic skin response (GSR) equipment and analyse the resulting data (Chapter 4). Ms. Marta Bortoletto and Ms. Katherine Baker informed me how to use event related potential (ERP) equipment. Mr. Oscar Jacoby instructed me how to use software for extracting data for ERP analyses that saved me considerable time. Professors Jason Mattingley, Charles Watson, and Michael Corballis, along with anonymous reviewers, provided comments for our comparative analysis involving apes detailed in Chapter 5. Finally, I would also like to thank the University of Queensland for providing me with a UQ Scholarship, as this allowed me to complete my thesis (and by extension this book) and still pay my bills!

CHAPTER ONE

AN OVERVIEW OF RESEARCH INVESTIGATING VISUAL SELF-RECOGNITION

The Importance of Visual Self-recognition and General Outline

This book is about our ability to recognize our own physical appearance (hereafter referred to as visual self-recognition; VSR). There are a number of reasons why VSR matters. Firstly, it provides the basis for our capacity to engage in image management. For many of us monitoring and maintaining our appearance is important and may ultimately contribute to reproductive success. Yet image management can also become detrimental to our health. People with eating disorders such as anorexia nervosa engage in dangerous eating habits because they perceive their own bodies-but not those belonging to others-to be larger than they really are (American Psychiatric Association, 2000; Sachdev, Mondraty, Wen, & Gulliford, 2008). A suicide rate 45 times higher than that for the American general population is associated with body dysmorphic disorder, a condition characterised by an acute disliking of one's own physical appearance (Philips & Menard, 2006). The importance of VSR, however, may go beyond image-management; it has been proposed to be a basis for identifying our potential kin and so may be critical to how we allocate resources and avoid incest (e.g., Hauber & Sherman, 2001; Platek & Kemp, 2009).

VSR may also be an empirical marker of complex psychological constructs such as the self-concept (i.e., having a sense of continuity, personal agency, and identity; Gallup, 1982, 1985, 1998), self-awareness (i.e., making one's self the object of attention; Gallup, 1982; Gallup, 1985, 1998; Keenan, Gallup, & Falk, 2004), or the 'collating mind' (i.e., generating and simultaneously holding multiple mental models; Perner, 1991; Suddendorf, 1999a; Suddendorf & Whiten, 2001). The assumption that VSR implies the presence of any of these constructs has raised ethical concerns. For instance, on the basis of their capacity to recognize

themselves in mirrors (and the assumption this involves self-awareness) it has been proposed that chimpanzees be granted human rights (Connolly, 2007; Gagneux, Moore, & Varki, 2005).[1] In summary, VSR is an important topic of research for reasons relating to image management, kin recognition, the study of complex cognitive constructs, and ethics.

It is for these reasons that an increasing number of neuroscientists are investigating the neural processes involved in VSR. The potential benefits of this endeavour are substantial and include (i) developing biological treatments for people with problematic conditions involving image management (Sachdev, et al., 2008), and (ii) furthering our understanding of the neural processes associated with the self-concept, self-awareness, or the collating mind (Devue & Bredart, 2011; Keenan, et al., 2004). Yet despite increased attention there is currently no consensus concerning the neural processes involved in VSR. For example, on the one hand some researchers have suggested recognizing images of self and other people involves *similar* neural processes (Sperry, Zaidel, & Zaidel, 1979; Tanaka, Curran, Porterfield, & Collins, 2006). On the other hand there are claims that recognizing images of self and others involves *different* neural processes (Brady, Campbell, & Flaherty, 2004, 2005; Keenan, Nelson, O'Connor, & Pascual-Leone, 2001; Preilowski, 1977; Turk, et al., 2002; Uddin, Rayman, & Zaidel, 2005). To further complicate matters, even if recognizing images of self and others does involve different neural processes there is still no consensus about the nature of these differences. For instance it has been reported that VSR predominantly involves (i) the right side of the brain (Keenan, Ganis, Freund, & Pascual-Leone, 2000b; Keenan, et al., 2000a; Keenan, et al., 1999; Keenan, Wheeler, Platek, Lardi, & Lassonde, 2003; Meador, Loring, Feinberg, Lee, & Nichols, 2000; Preilowski, 1977), (ii) the left side of the brain (Brady, et al., 2004; Turk, et al., 2002), and (iii) both sides of the brain equally (Brady, et al., 2005; Sperry, et al., 1979; Uddin, Rayman, et al., 2005).

A primary aim of the research documented in this book is to clarify these conflicting views about the neural processes involved in VSR; that is, I want to better determine whether recognizing images of self and others involves similar or different neural processes. Furthermore, *if* recognizing self and others does involve different neural processes I want

[1] This proposal was not successful. However, advocates are planning to appeal the issue within the European Court of Human Rights (Knight, 2008). I also note that organizations such as the Helsinki Group are advocating for the international abolition of research involving captive dolphins and that this too is partly based upon the supposed ability of dolphins to recognize themselves in mirrors (Grimm, 2011).

to specify *how* these processes actually differ. To address this a VSR task was designed in which participants had their brain activity measured whilst they identified images of faces belonging to themselves and a highly familiar other (their non-identical twin). If recognizing images of self and others involves similar neural processes, then similar patterns of neural activity should occur when comparing participants' responses to photographs of themselves and their twin. However, if recognizing self and others involves different neural processes, then different patterns of neural activity should occur when comparing participants' responses to photographs of themselves and their twin.

Another issue addressed in this book is whether the findings obtained from prior research can be generalized to common situations where we do see our own image. The basis of this concern is that despite the prominence of mirrors in developmental and comparative investigations of VSR–and in our everyday lives–prior neurological studies have used photographs taken from *one* moment in time instead. Moreover, when we do see ourselves in photographs they usually originate from a variety of different time periods (i.e., when the image was taken, such as a year ago, 10 years ago, etc.) rather than from a single moment in time. To address this issue two novel tasks were designed to test whether medium and time period influence the neural processes associated with VSR. One involved participants recognizing themselves in different media (i.e., mirrors and photographs). The other involved participants recognizing themselves in photographs taken from different time periods. If there is a single distinct neural signature of VSR, then it should be detectable regardless of whether media and time period are manipulated.

Finally, rather than relying solely upon human research to identify the neural features involved in VSR, a complementary approach proposed by Suddendorf and Collier-Baker (2009) was also pursued. Assuming closely related species that share the capacity for VSR also share its associated neurological features because of common descent, we can narrow down the search space for these features by identifying those that are only shared amongst related species that *do* show VSR when compared with their closest living relatives that *do not* show VSR.

In the sections that follow a brief history is provided about how VSR has been tested. Following this, Nikolaas Tinbergen's (1963) 'four questions' are described as they provide the broad investigative framework for my study of VSR. The VSR literature is then reviewed in relation to these four questions with particular emphasis given to neurological research. The final section details how the experimental and theoretical paradigms were executed within the remaining chapters of this book.

Irrespective of the current findings, I expect these paradigms will offer an important contribution to the field and therefore encourage their adoption by future researchers.

Measuring VSR: A Brief History

For nearly 200 years mirrors have been used to investigate VSR (e.g., Amsterdam, 1972; Darwin, 1872/1998, 1877; Gallup, 1970; Grant, 1828; Lacan, 2006; Preyer, 1889; Zazzo, 1948, 1979). Grant (1828) reported that when exposed to their own reflection, monkeys supposedly reacted with surprise, whilst an orangutan offered no reaction at all. However, Grant did not use a *systematic* approach to objectively address whether these animals were showing VSR. Charles Darwin (1872/1998, 1877) also made observations involving different species' reactions to a mirror. He indicated that two orangutans were incapable of VSR because after showing surprise and reacting as if being introduced to another orangutan (e.g., showing protruded lips, etc.), they became angry at their own image. However, Darwin (1877, *p*. 290) claimed his own nine month-old son was capable of VSR because:

> "…he associated his own name with his image in the looking-glass, and when called by name would turn towards the glass even when at some distance from it."[2]

Darwin's interpretations of these behaviours are problematic for a number of reasons. Firstly, basing his observations about human infants on his own children means that it is possible that he (unconsciously) gave his interpretations a favourable bias. Secondly, whilst the orangutans were only observed in front of the mirror during a single day, Darwin observed his son in front of a mirror for at least four months. Thirdly, Darwin used his son's name as a cue for testing VSR whilst there is no mention of any such verbal cue for the orangutans. In short, Darwin failed to use a *systematic* approach between species. Even in the event that *both* Darwin's son and the orangutans looked at the mirror upon hearing their names (or another verbal cue) this could be due to associative learning rather than VSR proper (Gallup, 1982). Nevertheless, Darwin's important methodological contribution to the study of VSR was that, for his son at least, he

[2] It is worth noting Darwin's claim that his son could recognize himself at age nine months is most likely incorrect, as subsequent (objective) research described below clearly indicates that children typically do not show VSR in mirrors until 18-24 months.

attempted to correlate reactions to mirrors with what he thought was another form of observable self-related behaviour (i.e., recognizing one's own name).

William Preyer (1889) took this correlational approach further in his own attempt to establish some milestones associated with children's development of self-awareness. Preyer (1889, *p*. 200) stated that VSR emerges at 17 months when:

> "…signs of vanity are perceived. The child looks at himself in the glass with pleasure and often. If we put anything on his head and say, 'Pretty,' his expression changes. He is gratified in a strange and peculiar fashion; his eyebrows are raised, and the eyes are opened wide."

Preyer claimed that such expressions coincided with the emergence of personal pronoun use and body exploration (e.g., sucking one's own toes). Nonetheless, like Darwin, his interpretations are potentially biased because they are based upon his own children. More importantly, his description of the facial expressions supposedly indicative of VSR are ambiguous at best, and therefore it is possible that other observers may give different interpretations other than vanity and VSR. In summary, despite their contributions to the study of VSR, Grant, Darwin, and Preyer all failed to formulate a *systematic*, objective approach to examining VSR. This issue continued to plague investigations of VSR for the next 80 years (e.g., Lacan, 2006; Zazzo, 1948, 1979).

The conceptual breakthrough finally came with Gordon Gallup's (1970) seminal research on chimpanzees. Gallup assumed that these apes were capable of VSR based on his observation that they used a mirror to manipulate parts of their own body that they would otherwise not directly see (e.g., the nostrils, anal-genital regions, etc.). To test his assumption Gallup devised the following procedure. The mirrors were removed and the chimpanzees anaesthetized. He then placed an odourless, tactile-free mark on areas that could only be seen with the mirror (i.e., the uppermost portion of their eyebrow ridge and ear). Four hours after the animals had recovered from the anaesthetic, the mirror was reintroduced for 30 minutes and their behaviour observed. Results indicated that, compared with the 30 minutes prior to the reintroduction of the mirror, self-directed responses to the marked areas significantly increased between four to ten times. In essence Gallup's 'mirror-mark test' was a simple yet revolutionary procedure that, by requiring mirror-mediated behaviour to an unexpected mark on the body, allowed for a *systematic* quantitative measure of whether VSR occurs.

Tinbergen's Four Questions: A Framework for Investigating VSR

The Nobel prize winning ethologist Nikolaas Tinbergen (1963) proposed that when we want to understand any particular behavioural trait there are at least four questions that should be asked: (1) *ontogeny* (how does the trait emerge within an individual's lifespan?); (2) *phylogeny* (how does the trait emerge within a species' evolutionary history?); (3) *underlying mechanisms* (how does the trait work?); and (4) *function* (what is the trait good for?). In the review that follows, when discussing the mechanisms associated with VSR, both the psychological and neurological literatures will be covered. Like most cognitive neuroscientists I believe that consideration of psychological processes can genuinely inform our understanding of neurological processes and vice-versa. This review will also consider Tinbergen's other three questions (i.e., development, evolution, and function). This Tinbergian approach provides the broad framework for identifying issues and perspectives that can further our understanding about the neural processes involved in VSR. In the final chapter I consider how the neurological findings reported here can, in turn, shed light onto the developmental, evolutionary, functional, and psychological aspects of VSR.

The Ontogeny of VSR: Evidence from Developmental and Clinical Psychology

The purpose of this section is to review what is known about VSR in relation to its development and some clinical conditions.

VSR in Children

Independently of Gallup, Amsterdam (1972) devised a similar procedure with mirrors to test for the presence of VSR in preverbal children by observing whether they could produce self-directed responses to an unexpected mark that was surreptitiously placed upon the forehead.[3] She reported that this behaviour began to occur between the ages of 18-24 months, and this finding has since been replicated numerous times despite some socio-cultural diversity (Asendoorpf & Baudonniere, 1993; Bard, Todd, Bernier, Love, & Leavens, 2006; Bertenthal & Fischer, 1978;

[3] For obvious ethical reasons the children were not anaesthetized like the chimpanzees in Gallup's study.

Chapman, 1987; Kartner, Keller, Chaudhary, & Yovsi, 2012; Lewis & Brooks-Gunn, 1979; Nielsen & Dissanayake, 2004; Nielsen, Dissanayake, & Kashima, 2003; Nielsen, Suddendorf, & Slaughter, 2006).

However, passing the mirror-mark test does not mean that children recognize themselves in *any* situation. Consider our experience as adults. There are at least two common contextual factors that are associated with most of the situations in which we see our own image. The first involves medium. Mirrors are likely to be the most common means by which we see our own appearance (Mita, Dermer, & Knight, 1977), but many of us also see ourselves in photographs and videos. Secondly, when we do see ourselves in non-mirror media this may involve images originating from different time periods (e.g., last year, when we were teenagers, etc.).

Do children who show mirror self-recognition also identify their appearance in other media and from different periods of time? Current evidence suggests this is not necessarily the case (Bigelow, 1981; Povinelli, Landau, & Perilloux, 1996; Suddendorf, 1999b; Suddendorf, Simcock, & Nielson, 2007). For example, despite passing the mirror-mark test by 24 months of age, only by 36 months have equivalent passing rates been found when children are presented with live video versions of the mark test (Povinelli, et al., 1996). Perhaps video images of self take longer to recognize because they are usually smaller than the image seen in a mirror. It is also possible that the direction of the video image is responsible, for unlike mirrors, videos involve reversing the left-right direction of the original image. Both these factors appear to be irrelevant, for despite using video images that were life-sized and mirror-reversed, equivalent passing rates between live video and mirror versions of the mark test still do not occur until children are 36 months of age (Suddendorf, et al., 2007).

Another factor that may contribute to whether VSR occurs in different media is one's expectations. For example, perhaps the perceptual quality of photographs is somehow poorer than in mirrors and therefore when children see themselves in photographs they see an image that does not resemble closely enough their expectations of what they think they should look like. Another possibility is that children are likely to have more experience with seeing their own image in mirrors than in either videos or photographs and this may lead to differences in their expectations about what they should see. Therefore, whilst they have appropriate expectations about seeing themselves in mirrors, this may not be the case in other media (Suddendorf, et al., 2007). Interestingly, Bedouin infants without any mirror experience–and hence no expectations about what should be seen when looking into a mirror-were still able to pass the mirror-mark test at

equivalent rates to those regularly exposed to mirrors (Bigelow, 1981). Although this indicates that expectations do not influence VSR in different media it is possible these Bedouin children had experience seeing their own reflection in other (non-mirror) reflective surfaces (e.g., glass, metal, etc.). The role of expectations for VSR in different media requires further attention.

Children also appear to be limited in their ability to recognize themselves from different time periods. For instance, children require an additional 24 months after passing the mirror-mark test before showing equivalent passing rates for video and photographic versions of the mark test involving three-minute delays (Povinelli, et al., 1996; Skouteris & Robson, 2006). It is possible that medium causes this difference, yet it must be noted that 36-month old children who passed live video versions of the mark test still required an additional 12 months before similarly passing the delayed version (Suddendorf, 1999b; Zelazo, Sommerville, & Nichols, 1999). Perhaps the crucial factor is the presence of contingency cues, which, in contrast to live videos, are absent in delayed videos. For example, Suddendorf (1999b) found that 3-year old children were equally poor at using delayed video for locating the mark upon their forehead and a hidden toy.[4] Another possible reason why children show VSR in one time period but not in another involves developmental differences in the self-concept (Povinelli, 2001; Povinelli, et al., 1996). I will describe this possibility in more detail below when discussing the psychological models proposed for VSR.

VSR in Clinical Conditions

There are clinical conditions when VSR is characterized by extreme (mis)interpretations of the perceived image. Examples include anorexia (when people perceive their own appearance to be much larger than it actually is; Friederich, et al., 2010), and body dysmorphic disorder (when

[4] Povinelli (2001) suggests otherwise based on his observation that 3-year old children successfully used delayed videos to locate a hidden puppet. In other words, while most 3-year olds do not pass the delayed video version of the mark test, they are at an age when they appear to understand the correspondence between delayed video and reality (Povinelli, 2001). However, the hidden toy experiment referred to by Povinelli did not include a delayed video version of the mark test, whilst the experiment by Suddendorf (1999b) included the mark and hidden toy tests. Povinelli claims that Suddendorf's failure to observe 3-year olds locate the hidden toy was likely due to the video footage not being mirror-reversed. This issue remains unresolved.

people (mis)perceive a serious defect in their own physical appearance; Feusner, Yaryura-Tobias, & Saxena, 2008). There are also clinical conditions when VSR is absent for all or some aspects of one's own appearance. This may occur in prosopagnosia (when people do not recognize the facial features belonging to themselves or someone else they know; Damasio, Tranel, & Damasio, 1990; de Ajuriaguerra, Strejilevitch, & Tissot, 1963; Klein, Gabriel, Gangi, & Robertson, 2008); Capgras delusion (when people believe that an image of themselves or someone else they know is an image of an imposter; Hirstein & Ramachandran, 1997); asomatognosia (when people perceive a part of their body is not their own; Paysant, Beis, Le Chapelain, & Andre, 2004); illusory reduplication (when people recognize someone else as self; Blanke, Arzy, & Landis, 2008); and mirrored self-misidentification (when people do not recognize their own image in a mirror; Biringer & Anderson, 1992; Biringer, Anderson, & Strubel, 1988; Bologna & Camp, 1997; Breen, Caine, & Coltheart, 2001; Connors & Coltheart, 2011; Phillips, Howard, & David, 1996).[5] Interestingly, healthy individuals may also have transitory experiences similar to the conditions just mentioned (Barnier, et al., 2008; Bredart & Young, 2004; Connors, Barnier, Coltheart, Cox, & Langdon, 2011; Connors, Cox, Barnier, Langdon, & Coltheart, 2011).

As with children, several adult patients have been reported to recognize themselves in one medium but not another.[6] For example, the Capgras patient known as "D.F" recognized himself in mirrors but not in photographs (Hirstein & Ramachandran, 1997). Several Alzheimer's patients have also been noted to self-recognize in mirrors but not in videos (Biringer & Anderson, 1992). Similarly, there have been reports that people with asomotagnosia may recognize their affected limb in mirrors but not when seen directly (Paysant, et al., 2004). Contrary to this some people with asomotagnosia have been observed to experience their

[5] Rather than being a neurological oddity, the prevalence of mirrored self-misidentification or illusory reduplication has been estimated to be as high as 2-10% of the population suffering Alzheimer's dementia (Burns, Jacoby, & Levy, 1990; Deutsch, Bylsma, Rovner, Steele, & Folstein, 1991; Forstl, Burns, Jacoby, & Levy, 1991; Hyodo, et al., 2005; Mendez, Martin, Smyth, & Whitehouse, 1992; Rubin, Drevets, & Burke, 1988). Furthermore, this number increases with disease progression: all those classified as being in a moderate stage of dementia were observed to pass the mirror-mark test, yet only 75% passed when categorized as being moderately severe.

[6] It should be noted that with the exception of the study by Biringer and Anderson (1992), none of the clinical research I discuss below used mark tests, but instead observed whether participants (i) named their own image, or (ii) misidentified other people as themselves.

delusion only when using a mirror (Paysant, et al., 2004). There have also been at least three instances where people with mirrored self-misidentification (case studies F.E, M.M, and E.F) recognized themselves in photographs (Breen, et al., 2001; Phillips, et al., 1996; Villarejo, et al., 2010). More research involving clinical patients, and comparing these patients to healthy people, should shed light on how media influences the neural processes involved in VSR.

To date only one study involving clinical participants has directly tested for VSR in different time periods. Case study P.H, an 83-year old with Alzheimer's dementia, was only able to recognize herself in photographs taken during her 20's and 30's (Hehman, German, & Klein, 2005). It is possible that time period is the underlying factor in the clinical cases described above where VSR occurs in one medium but not another. For example, case D.F was presented with photographs taken two years prior to his test (Hirstein & Ramachandran, 1997), case M.M was presented with photographs ranging from one to ten years prior to testing (Villarejo, personal communication), and the Alzheimer's patients were presented with video images of themselves taken two weeks prior to testing (Biringer & Anderson, 1992). It remains unknown how recent the photographs were when testing cases F.E and E.F (Breen, et al., 2001; Phillips, et al., 1996). More research using live versus delayed video versions of the mark test may assist researchers in knowing whether time period influences VSR in clinical populations.[7] Comparing clinical and healthy adults on delayed mark tests and/or using images from specific time periods may also contribute to our understanding of the neural processes involved in VSR for images taken from across the lifespan.

The Ontogeny of VSR: Summary

Children typically begin to recognize their image in a mirror between the ages of 18-24 months. VSR in live and delayed videos emerges after recognition in mirrors, between 36-48 months. There are clinical conditions that affect VSR such as anorexia, body dysmorphic disorder, asomotagnosia, and mirrored self-misidentification. Some clinical patients exhibit a capacity for VSR that is influenced by whether they see themselves in mirrors or photographs, or in photographs from different time periods. Crucially, these developmental and clinical findings together

[7] Two studies comparing healthy children with those who have an Autistic Spectrum Disorder have found no difference in their passing rates for delayed versions of the mark test (Dissanayake, Shembrey, & Suddendorf, 2010; Dunphy-Lelii & Wellman, 2012).

indicate that medium and time period may influence the neural processes involved in VSR.

The Phylogeny of VSR: Evidence from Comparative Psychology

This section considers evidence about the evolutionary history of VSR. I will first outline the empirical facts about which species can and cannot recognize their physical appearance. Based upon this information I then offer a phylogenetic reconstruction of how and when this ability most likely evolved.

Fact Finding: Which Species Show VSR?

Following Gallup's (1970) initial study on chimpanzees, comparative researchers attempted to identify whether other species are capable of VSR. Primates that have *repeatedly* passed the mirror-mark test include all genera of the great apes (i.e., chimpanzees, gorillas, and orangutans; Bard, et al., 2006; Boysen, Bryan, & Shreyer, 1994; Calhoun & Thompson, 1988; Gallup, 1970; Gallup, McClure, Hill, & Bundy, 1971; S. Hill, Bundy, Gallup, & McClure, 1970; Lin, Bard, & Anderson, 1992; Miles, 1994; Parker, 1994; Patterson & Cohen, 1994; Posada & Colell, 2007; Suarez & Gallup, 1981; Swartz & Evans, 1991, 1994). This does not mean *all* individuals within these genera passed the test. For example, it has been estimated that of those tested only 43% of chimpanzees, 50% of orangutans, and 31% of gorillas have passed (Swartz, Sarauw, & Evans, 1999). This may be due to several factors including differences in motivation, rearing conditions, sample size, and age (De Veer & Van Den Bos, 1999; Suddendorf & Whiten, 2001). Another factor is the different passing criteria used by various researchers: some have operationalized 'passing' as touching the mark more in the presence of the mirror than without the mirror (e.g., Gallup, 1970), whilst others require an initial period of five bouts of mirror self-exploration that lasts at least 30 seconds, followed by a minimum of eight mirror directed mark touches (Povinelli, Rulf, Landau, & Bierschwale, 1993).[8] Regardless of intraspecies

[8] It is worth noting that unlike comparative researchers, developmental researchers have also interpreted pointing and verbal labelling (e.g., 'me' or their own name) as evidence for passing the mark test. Despite such methodological differences between species, when a uniform procedure was used between human and chimpanzee subjects similar results were obtained (Bard, et al., 2006).

variation and its causes, it is clear that all genera of the great apes possess the capacity for mirror self-recognition. No other primate species have provided *replicated* instances of passing the mirror-mark test. This includes the small apes (i.e., gibbons and siamangs; Lethmate & Dücker, 1973; Suddendorf & Collier-Baker, 2009) and several species of monkey (Anderson & Roeder, 1989; Benhar, Carlton, & Samuel, 1975; Gallup, 1970; Lethmate & Dücker, 1973; Macellini, Ferrari, Bonini, Fogassi, & Paukner, 2010; Mitchell & Anderson, 1993; Rajala, Reininger, Lancaster, & Populin, 2010; Suarez & Gallup, 1986).[9]

Many non-primate species have also been investigated without the mark test to see whether they have the capacity for self-recognition in mirrors. These include dogs (Zazzo, 1979), fish (Desjardins & Fernald, 2010; Lissmann, 1932; Tinbergen, 1951), sea lions (Delfour & Marten, 2001), and various types of birds (Andrews, 1966; Censky & Ficken, 1982; Diamond & Bond, 1989; Gallup & Capper, 1970; Pepperberg, Garcia, Jackson, & Marconi, 1995). These species appear to either ignore their own reflection or react towards it as if it were a conspecific. There is some evidence that both killer and false killer whales engage in contingency testing whereby they learn the correspondence between their own movements and the moving image seen in the mirror (Delfour & Marten, 2001). Although contingency testing may be a necessary prerequisite for mirror self-recognition, evidence with human infants suggests that despite showing contingency testing at age five months, they nonetheless fail to pass the mirror-mark test until aged 18-24 months (Bahrick & Watson, 1985). Therefore contingency testing in whales remains ambiguous evidence for VSR unless complemented by passing the mirror-mark test. This has been attempted: one killer whale removed the mark by rubbing itself against the pool wall but unfortunately there was no baseline period to compare this mark rubbing against (Delfour & Marten, 2001).

Pigeons were initially reported to pass the mirror-mark test (Epstein, Lanza, & Skinner, 1981), yet in this instance the pigeons were conditioned over hundreds of trials to peck at the sight of marks. This is contrary to Gallup's original observation involving apes passing spontaneously. Furthermore, attempts to replicate the results for pigeons reported by Epstein and colleagues have failed (Thompson & Contie, 1994). Two

[9] A recent study has claimed that rhesus monkeys can be trained to acquire mirror and video induced self-directed behaviours (Chang, Fang, Zhang, Poo, & Gong, 2015). However, this involved extensive conditioning reminiscent of Epstein and colleague's pigeon study (1981), and is therefore, in my opinion, subjected to similar criticism (see below).

individuals of another bird species, the European magpie (Prior, Schwarz, & Gunturkun, 2008), have also supposedly passed the mark test. Although these birds showed more mark directed behaviour in the mirror versus no mirror condition, it was noted that one of them also showed mark directed behaviour when wearing a sham (i.e., a mark they could not see). This suggests that these birds may have been responding to the sensation of the mark rather than its appearance. There is conflicting evidence for Asian elephants with one study reporting that they could not pass (Povinelli, 1989) whilst another suggested that one individual could pass (Plotnik, de Waal, & Reiss, 2006).[10] Finally, one dolphin spent more time looking at the marked areas on its body in the mirror than when there was no mirror (Reiss & Marino, 2001). These are all intriguing findings, yet all require more stringent control conditions or replication to ensure their validity. Until then the current evidence supports Gallup's (1970) original contention that the capacity for mirror self-recognition is restricted to the great apes.

It remains to be established whether *any* (non-human) animal can recognize their own physical appearance in either videos or photographs. There are reports involving animals exposed to live videos. For instance, chimpanzees and orangutans used video to correctly locate hidden objects (Menzel, 1985; Poss & Rochat, 2003), whilst Japanese macaques used video to guide their hands to hidden food (Iriki, Tanaka, Obayashi, & Iwamura, 2001). Monkeys have also produced different looking patterns when viewing videos of self and conspecifics (Neiworth, Anders, & Parsons, 2001; Washburn, Gulledge, & Rumbaugh, 1997), and contingency testing has been observed with both monkeys and dolphins (Anderson, Kuroshima, & Paukner, 2009; Marten & Psarakos, 1995). Unfortunately, none of these behaviours suffices as strong evidence for VSR. Using videos to locate objects does not necessarily mean VSR has occurred because there are monkeys that can similarly locate objects using mirrors despite not being able to pass the mirror-mark test (for discussion see Gallup, 1982). Human children have similarly been observed to locate objects using video despite not passing the video mark test (Povinelli, et al., 1996). As for differences in looking patterns, one possibility is that this could simply indicate the images of self are treated as unfamiliar rather than familiar. Finally, as already mentioned above, we know from

[10] Upon personally viewing the video of this elephant I note that the supposed mark touching was rather unconvincing–there was no precision-when compared to other instances where elephants use their trunks to manipulate objects (e.g., they can pick up a grain of rice from the ground).

developmental findings that contingency testing is insufficient (although perhaps necessary) for self-recognition in mirrors (Nielsen, et al., 2006).

More convincing evidence involves chimpanzees using video to explore otherwise unobservable regions of their body (e.g., inner throat and anal-genital manipulation, etc.; Hirata, 2007; Savage-Rumbaugh & Rubert, 1986). Indeed, this behaviour is reminiscent of Gallup's (1970) initial observations involving chimpanzees' reactions to mirrors. However, this too requires confirmation with a mark test. This has occurred with one chimpanzee (Suddendorf, Simcock, Nielsen, & Collier-Baker, 2006), but must be considered as tentative until replicated.[11] Japanese macaques reportedly used one hand to touch a transient laser mark that appeared on their other 'televised' hand (Iriki, et al., 2001). Regrettably, no baseline data involving laser touching were included, nor has there been a replication. To summarize, it is clear that more mark test data are required to find whether humans are the only species that can self-recognize in media other than mirrors. This in turn may shed light on whether the psychological mechanisms underlying VSR in humans and the other great apes somehow differ.

Evidence is scant on whether animals can recognize themselves in images from different time periods. One study found that monkeys spent more time looking at live versus delayed video images of themselves (Anderson, et al., 2009). Compounding the issue of what this viewing difference actually means, such findings are largely irrelevant for addressing the issue of VSR across time periods because the temporal delay involved did not exceed one second. Gorillas were observed to show more interest in live videos compared with images recorded the day before (Law & Lock, 1994), yet there is no clear evidence that VSR occurred in either condition (i.e., there was no mark test). A more intriguing finding involves the sign-language trained gorilla Michael who reportedly signed "think that Michael me" when presented with his own photograph (Patterson, 1978). Similarly, when asked to sort photographs into different categories the chimpanzee Vicki supposedly placed her own photograph into a human rather than an animal pile (Hayes & Hayes, 1953). Both these accounts are anecdotal and have yet to be replicated. The temporal origins of these photographs were also not detailed. Ideally, video or photographic mark tests involving temporal delays similar to those employed with children (e.g., three minutes) will provide more compelling data for VSR across time.

[11] This has been attempted with one other chimpanzee, along with one gorilla and two orangutans. Results are inconclusive as they failed to pay sufficient attention to the video (Suddendorf & Collier-Baker, personal communication).

Phylogenetic Reconstruction of VSR

Based on current evidence involving the mirror-mark test Suddendorf and Whiten (2001) argued that the distribution of VSR in mirrors amongst primates may be explained in two ways (see Figure 1-1). The mechanisms underlying this ability may have been the result of *convergent* evolution in the ancestors of each of these species. That is, natural (and/or sexual) selection independently led each hominid species (i.e., humans and the other great apes) to evolve the trait–this implies at least four separate occasions of acquisition. Alternatively, given that the small apes have not shown evidence for VSR in mirrors, the trait may have evolved only once in the common ancestor of all hominids. This is a simpler explanation because only one assumption has to be made about events in the past: a common ancestor of hominids originally evolved the capacity between 14 and 18 million years ago, after the split of the line that led to modern small apes (i.e., hylobatids: gibbons and siamangs) but before the split of the line that led to modern orangutans. It is more parsimonious to assume that the capacity for VSR in mirrors shared by hominids is a homologous trait.

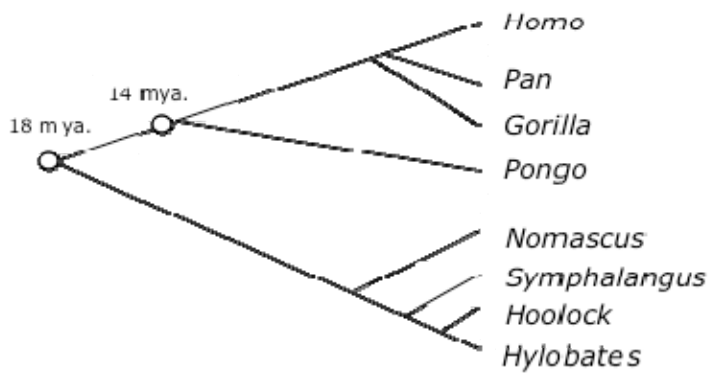

Figure 1-1. The phylogenetic tree of hominoids (i.e. great apes [*Homo, Pan, Gorilla, Pongo*] and small apes [*Nomascus, Symphalangus, Hoolock, Hylobates*]. Reproduced with permission from Suddendorf and Collier-Baker (2009).

The Phylogeny of VSR: Summary

VSR has been extensively studied in humans and non-humans. On the basis of replicated studies involving the mirror-mark test, current evidence indicates only hominids can recognize themselves in mirrors. More comparative research involving VSR in other media and from different time periods is required. A phylogenetic reconstruction of VSR in mirrors suggests that it is most likely a homology involving a common hominid ancestor that appeared after the line leading to the small apes.

Psychological Models Proposed for VSR

The purpose of this section is to review possible psychological mechanisms associated with VSR. *What does the ability for VSR tell us about the mind of the individual person or species in general*? It is this question that has motivated most researchers to investigate VSR (Bard, et al., 2006; Biringer & Anderson, 1992; Brady, et al., 2004; Gallup, 1982, 1985, 1998; Keenan, et al., 2004; Kircher, et al., 2000; Platek, Keenan, Gallup, & Mohamed, 2004; Platek, et al., 2006; Platek, Wathne, Tierney, & Thomson, 2008; Preilowski, 1977; Sperry, et al., 1979; Sui & Han, 2007; Sui, Liu, & Han, 2009; Taylor, et al., 2009; Uddin, Kaplan, Molnar-Szakacs, Zaidel, & Iacoboni, 2005; Uddin, Rayman, et al., 2005). Several cognitive and affective proposals have been made, yet it remains contentious which of these–if any–best accounts for the ability to recognize one's own physical appearance.

Cognitive Explanations for VSR

Cognitive models proposing to explain how VSR occurs can be categorized along a continuum from 'lean' to 'rich' (Bard, et al., 2006; De Veer & Van Den Bos, 1999; Nielsen, et al., 2006; Suddendorf & Butler, 2013, 2014). Lean proposals involve simple associative learning accounts rather than *any* mental model (or representation) about how one looks. For instance, Epstein and colleagues (1981) propose that passing the mirror-mark test requires nothing more than contingent reinforcement acquired through repetitive learning. Yet contrary to any repetitive learning, animals and children pass the mirror-mark test spontaneously (Gallup, Anderson, & Shillito, 2002). Another lean account is Heyes' (1994, 1998) proposal that VSR is nothing more than a by-product of the ability to distinguish between sensory information originating from within our body and sensory information from an external source. This proposal does not

explain the *inability* of human neonates to pass the mirror-mark test despite being able to distinguish between external and internal sources of somatic stimulation (Rochat & Hespos, 1997). Moreover, many species can differentiate between internal and external stimulation so this proposal does not explain why only a few species pass the mirror-mark test. Lastly, it has nothing to say about the ability for VSR in other media such as photographs and delayed videos.

Mitchell's (1997) kinaesthetic-visual-matching theory is another lean proposal in which mirror self-recognition is thought to result from contingency testing; that is, matching the sensation of moving with the simultaneous movement of the image seen in the mirror. However, as discussed above, humans show contingency matching at five months of age (Bahrick & Watson, 1985) and therefore Mitchell's proposal fails to account for the absence of VSR in humans until age 18 months. It also fails to explain the ability for VSR in other media.

The most prominent 'rich' proposal is that of Gallup (Gallup, 1970, 1982, 1985, 1998) who argues that VSR presupposes self-awareness, which he defines as "the ability to become the object of your own attention…" (1985, *p*. 633). His reasoning is as follows. Similar motor-perceptual abilities are shared by many species regardless of whether they pass the mirror-mark test (e.g., monkeys can use a mirror to locate food and differentiate between external versus internal sources of stimulation). These abilities, whilst necessary, are not in themselves sufficient for VSR. The differentiating factor between these species must therefore be a representational one. More specifically, recognising our own image requires a *self-concept* because we can only correctly infer that the reflected image in the mirror is our own-and not someone else's-if we have:

> "…a sense of continuity, a sense of personal agency and a sense of identity" (Gallup, 1998, *p*. 240).

Gallup ultimately argues it is self-awareness that allows ourselves to construct and access this self-concept:

> "Individuals who are self-aware...experience a sense of psychological continuity over time and space" (1998, *p*. 240).

He also proposes that self-awareness forms the basis for the ability to reason about our own mental states (along with our own impending deaths), and this subsequently allows us to reason about the mental states

of others (i.e., theory of mind; Gallup, 1982, 1985, 1998).[12] In summary, Gallup claims that VSR presupposes self-awareness at a very broad level (Gallup, Platek, & Spaulding, 2014).

Evidence supporting Gallup's proposal involve correlations between mirror self-recognition and other indicators of self-awareness. For example, it has been reported that children who pass the mirror-mark test show embarrassment, which is an emotion involving self-directed attention (Amsterdam, 1972; Lewis, 1994, 1997). Children who pass the mirror-mark test, compared with those who do not, are also more likely to use personal pronouns (i.e., 'I', 'me', and 'mine'; Lewis & Ramsay, 2004). Similarly, Chantek-a language trained orangutan-used more frequent pronoun signs after developing mirror self-recognition (Miles, 1994). There is also evidence for a relationship between VSR and theory of mind. Johnson (1982) reported that 18-24 month-old human infants passing the mirror-mark test were more likely to show altruistic behaviour towards their mothers when pretending to be distressed. Gallup and colleagues (2002) state that this altruistic behaviour is a proxy for theory of mind because one can only show altruism if one has the ability to reason that the mental state of another person involves suffering.

Gallup's proposal nevertheless remains problematic. If having a self-concept means at least having a sense of *identity* and *continuity* through time (Gallup, 1985), then it should be the case that infants recognise their own image regardless of whether the image they are confronted with corresponds to the 'here and now'. Yet the delayed feedback video version of the mark test is harder for children to pass than both the mirror-mark test and the live video version (Povinelli, et al., 1996; Suddendorf, 1999b; Suddendorf, et al., 2007). In addition, some mirrored self-misidentification patients continue to groom themselves using mirrors (e.g., Breen, et al., 2001). This is surprising if we assume that such grooming involves at least a sense of *personal agency*–which is the other main component of the self-concept proposed by Gallup (1985). There is also evidence which appears to be inconsistent with Gallup's proposal that self-awareness is required to construct and access the self-concept: people with impairments in episodic memory–which involves self-awareness about personal past events-are still able to acquire and access personal information about who they are (for a review see Klein & Gangi, 2010). Finally, death awareness-which Gallup associates with self-awareness-does not maturely develop in

[12] Gallup (1982, 1998) proposes that self-awareness subsumes both consciousness (i.e., being aware of your own existence) and mind (i.e., being aware of your own mental states). Evidence for consciousness or the mind is therefore, according to Gallup, evidence for self-awareness.