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Brain Activity Measurement in Gaming: Baming

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Abstract

A brief review connecting aspects of game theory, game refinement theory, and brain imaging of players while gaming was undertaken to highlight arcs of discovery underway. We will show that fNIRS is a heretofore underused brain measurement technology; that game theory concepts have suffered from a dearth of experimental evidence, but also that f NIRS has already been used to produce significant results in experiments involving players during gaming. This research shows that since all three are true, experimentation using fNIRS presents as a promising avenue for improving and expanding on standard and emerging concepts in game theory and recreational game studies. We develop this idea and call it BAMING--brain activity measurement in gaming, and propose the next in a series of fNIRS BAMING experiments.

Key Words: *Game Refinement Theory, Game Theory, General Gaming, fNIRS, Superior Frontal Gyrus.*

Introduction

The study of games has been a major contributor to the gains in computer hardware and programming in recent decades, and to the body of knowledge of strategic decision-making for politics, finance, economics, games themselves, and many other fields. Game theory (GT) has provided a host of new topics and applications. Today GT is a multifarious hybrid science benefitting from the gains in programming and artificial intelligence (AI) which it helped to foment. Information science, neuroscience and evolutionary biology are a few of the fields to share in the bounties of game science. It is reasonable to expect valuable new insights from the continued study of games. Game Refinement Theory (GRT) considers the role of information complexity in the search space in games.

Claude Shannon began the age of computer gaming with a 1950 paper outlining a sample evaluation function for chess. What ensued was said to be the world's longest running computer experiment, ending in 1997 with the triumph of Deep Blue over Gary Kasparov. Because of its development with the computer chess problem, recreational game science was almost synonymous with AI in the latter half of the 20th century. Game Refinement Theory continues its expansion into the study of other games, like shogi, go, mah jhongg, and more recently into video games and sports. We hope this leads toward a workable general gaming model, which will be something analogous to strong AI in games. The present research is a small step in that direction. This paper explains Game Refinement Theory in the framework of traditional game theory, and points to the intersection of fNIRS brain measurement and games as an expanding field with excellent potential for game scientists. Prior studies have been carried out in the established frameworks of cognitive neuroscience or neurology. This group investigates games as forms of human and machine intelligence, for the purpose of understanding the fundamentals of games in general. The well-developed model of games as a vehicle of experimentation for cognitive neuroscientists is being established, and we recommend games for those engaged in brain studies, as with brain activity measurement for those in the research of AI and games.

Literature Review for Experimentation in Game Theory and Game Playing

Brain measurement experiments of players engaged in social dilemma and other economic games have been well underway for over a decade (Breiter et al., 2001; Rilling et al., 2002). Grether et al. (2007) contains a convincing call for functional brain experiments in economic games, which could be extended to recreational games as reasonable proxies, if not direct measurements, of general game behaviour. Functional brain activity measurement of players during gaming (BAMING) has begun to show some benefits in several related fields. Since the beginning of the new millennium, findings from BAMING have led to better models of cognition, deeper understanding of social behaviour, more and better maps of human brain connectivity and function, and improved methods and analytics. A few mentionable works include the subjects of brain measurements during currency auctions (Grether et al., 2007), reciprocity in the context of social dilemmae (Nagatsuka, Shinagawa, Okano, Kitamura & Saijo, 2013; Rilling et al., 2002), the ability of players to perform under stress (Izzetoglu, Bunce, Onarel, Pourrezaei & Chance, 2004), and various recreational gaming functional brain studies, like (Mathiak et al., 2011, Matsuda & Hiraki, 2006; Saito, Mukawa & Saito, 2007). There are implications for these advancements in brain-to-machine interfaces, affective gaming, neural connectivity studies, and research on the disabled, to name a few (Hoshi et al., 2011; Matthews, Pearlmutter, Ward, Soraghan & Markham, 2008; Ono et al., 2014; Tan & Nijholt 2010; Tachtsidis & Papaioannou 2013; Volz, Schubotz & von Cramon, 2005). Each one urges caution in making the correct conclusions about results from fNIRS, while recognising the potential pitfalls for this admittedly very promising, nascent technology. One of the most basic goals of these and most brain studies has been identifying regions of interest (ROI) by measuring neural activation with reference to various cognitive tasks. In one sense, the present research proposes to continue on that same path. In another sense, functional brain measurement during gaming has tended to focus on finding some effects of video gaming or achieving a deeper understanding of the gamers through the lens of games. Rather than with an eye only to the gamer, we plan to look at these relationships in the context of game information, and the design giving rise to that information.

Research Questions

We would like to open the investigation to see whether functional brain measurement of human players can support one of the emerging points in the study of Game Refinement Theory, critical positions in games (CPGs). Critical positions are, as suggested, a moment of crises, or perhaps more aptly the moment when the resolution of crises manifests. CPGs hold possible significance in many areas in human behaviour. Because the CPG describes a moment of change from a player's focus on evaluating and deciding moves to something else, namely resignation or victory, we expect results indicating a change from high-level, top-down regulatory mechanisms during play, as per Ono et al. (2014), with a return to more middling levels after most of the information of winning or losing is presented.

As a pre-requisite to being able to investigate the happenings in the mind during CPGs, we need to be able to time those positions, and quantify them in the framework of the game. Game Refinement hypothesizes that the branching factor and length of game (i.e., the quantity of game information) and any changes to the velocity with which that information flows is directly related to the entertainment value of the game. It is strongly believed that wins and losses in recreational games correlate with the powerful emotional signals found in association with monetary gains and losses (e.g. Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001), which remains to be proven. Particularly for this study's purpose, the acceleration of information near game's end culminates when the certainty of game outcome reaches some reasonable level. Merely reaching that "reasonable" level of information of game outcome belies the nature of the endgame somewhat, given that this passage almost always occurs in the presence of a steep sweeping curve (see Figure 1; Figure 3.a. and b.). There have been no studies done presenting any direct physical evidence of a causal relationship between information acceleration at endgame, and a feeling of excitement or entertainment. This study identifies a way to partially validate those claims.

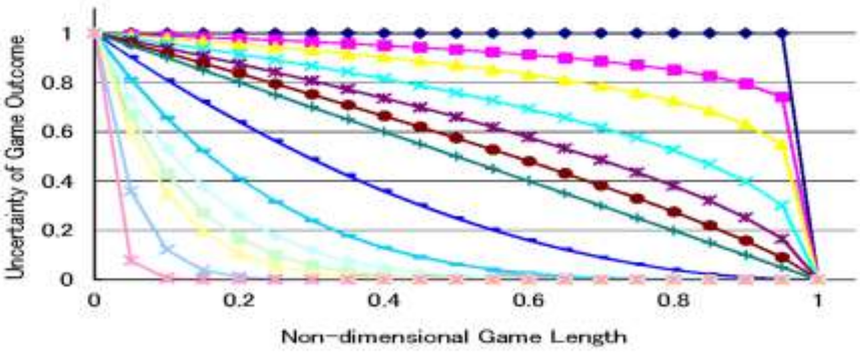


Figure 1. Uncertainty of game outcome—One reason games are entertaining for people is that they have a great deal of uncertainty until the final moments. Steadily progressing uncertainty of game outcome, shown as the green 45° curve, and games which progress quickly to certainty of game outcome (concave curves) are less entertaining (Majek & Iida, 2004, Iida, Nakagawa &Spoerer, 2012)

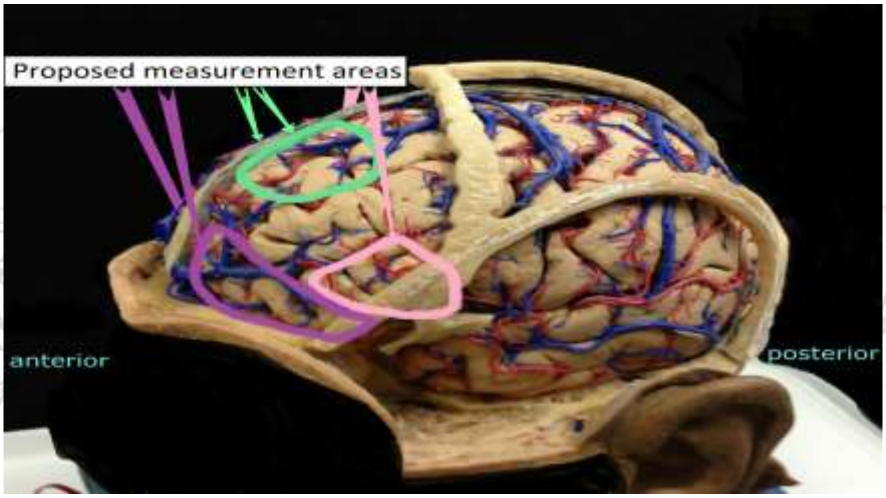


Figure 2. A visual for alignment of the mobile wireless fNIRS headset over the L and R superior frontal gyri. To highlight the relationship of the outer surfaces to the underlying cortical structures, the cranium is removed from the supraorbital process and along the zygomatic arch and zygomatic process. The coronal suture, superior temporal line and pterion are replaced as landmarks (Photo by Nathan Nossal).

The item we plan to look for in the context of the whole game is the critical position in the end game—using the blood oxygen record of players as a marker, exactly when does the information of winning or losing accelerate beyond reasonable expectation of return? Information of the game and its outcome is encoded somewhere in the brain. Girouard et al. (2009) proved this dramatically with the successful use of fNIRS to evaluate player experience of a Pac-Man® game. We know that the critical moment must come when players (or observers) greet victory and acknowledge defeat. We suppose that this moment comes prior to the end of game, and that the event manifests physically in the prefrontal cortex (PFC) as well as autonomic structures. It might also include the relaxation of input from the sympathetic nervous system and calming responses of the parasympathetic nervous system, as like post-acute stress response (Jansen, Nguyen, Karpitsky, Mettenleiter & Loewy, 1995; Olpin & Hesson, 2013). The primary neural actors for that response, the amygdala, hypothalamus and pituitary gland are too deep in the brain to be directly measured by fNIRS, however we are also interested in the significations of that event in the areas of the outer cortex. fNIRS can detect blood-oxygen level dependent (BOLD) signal changes in the outer cortical areas of the forebrain (as in Figure 2) where it has been shown to be effective for locating indicators of higher cognition, and emotion (Ferrari & Quaresima, 2012; Strait & Scheutz, 2014). There are also several other well-known biological indicators for excitement such as heart and breathing rates, sphincter flexion, pupil dilation and vasodilation.

Theoretical Framework

Game Theory

Cardinal utility functions describe fully known information, such as that in a complete game tree. They also provide the mathematical basis for opponent modeling used in recreational gaming and artificial intelligence. When the whole tree, and utility index are not known, or are impractical, heuristic searches employ evaluation functions, which are faithful representations of the utility functions. In turn, knowledge of the opponent's evaluation functions form the heart of opponent modelling (Burns & Roszkowska, 2005; Gao, Iida, Uiterwijk & van den Herik, 2001). A player who correctly estimates his opponent's proclivities puts him/her/itself at a distinct advantage in any game. As could be imagined, opponent modelling works well in computer games or board games, where the rules are tightly constrained, well defined and relatively simple. Trying to identify and measure players' preferences is considerably more difficult where the wider spectrum of human relations are concerned. (For example the potentially endless loop of calculations beginning "I think that you think, that I think…") As noted by Ross (2010) people should understand that "game theory isn't useful for modelling every possible empirical circumstance that comes along."

During the first three decades of GT, theorists worked on expansion, producing cross-overs involving economic behaviour, war strategy, diplomacy, evolutionary biology and more. During that time, few experiments were conducted in game theory despite acknowledgements of this deficiency by its very inventors. It had become clear that individuals choose in ways counter to that predicted in, e.g. the PD game, too frequently to be considered anomalies. This apparent lapse of self-interest in games has been misnamed "altruism" such as in the case of making a move that is costly to oneself for the purpose of reciprocating goodwill or punishing the ill-will of other players. Nash's equilibrium (Nash, 1951) received attention from statisticians like McKelvey and Palfrey (1995) to address probabilistic variability, offering the quantal response model. Recent decades have produced experiments leading to many substantial refinements in game theory, utility theory, and the assumption of rationality (Ahn, Ostrom & Walker, 2002; Axelrod, 2000; Breiter et al., 2001). The 2000's are a heyday for GT experimentation. As it turns out, one-shot games are not actually very common, with repeated games being more the rule, whether in the marketplace, diplomacy, or on the chess board. This simple fact alone affects games in a number of most significant ways.

Colin Camerer summarizes the defence of some game theorists to GT refuters "If people don't play the way theory says, their behaviour has not proved the mathematics wrong," he says "any more than finding that cashiers sometimes give the wrong change disproves arithmetic." However, this is only true in the strictest of descriptive terms. If it is not already obvious, the inaccuracy of this analogy is that arithmetic is not a study in how cashiers behave. Normative GT is, however, a study of behaviour in games, often human behaviour, and an application of the concept of rationality. Only in so far as game theorists are not trying to predict, engineer, or model any behaviour or economic activity is theirs a purely mathematical concern (Guala, 2006). Quoting Camerer (2011, p. 3) "It is important to distinguish *games* from *game theory*." Game Refinement Theory tends towards the former category. In recreational games, theorists want to discern the meaning of the discrete game information comprising the building blocks, nuts and bolts that hold up all games.

Game Refinement Theory

Many of the discussions about the assumptions of rationality and self-interest, altruism and moral dilemmas posed in normative GT do not appear as topics for the recreational games which occupy the remaining part of this work. Board games are objectively simple, usually two-agent "zero-sum" games. These have a clear objective and tightly constrained number of variables, providing know-able search complexity and informational game length. Hundreds of years before serious inquiries were being made in mathematical game theory, game masters of antiquity were cataloguing their knowledge of plays and strategies in board games, such as those by Lucena in chess, and Ohashi or Kanju in shogi. They are also our philosophical antecedents.

We admit that attempting to completely separate normative and descriptive GT constructs would be illusory. For its part, Game Refinement Theory (GRT) is first and foremost a mathematical treatment of games, on the cut-and-dry descriptive side. On another level though, we wish to consider the implications of game refinement findings for human factors in art, entertainment and emotion, which are definitions of rationality, hence normative. GRT provides measurability to entertainment factors as well as providing game data and theory for other areas of GT. Until now, GRT experimentation has relied primarily upon modelling, interpretation of game data, and surveys, primarily for relatively easy-to-measure board games. Each of these has produced such results as identifying fundamental game patterns, game progress, evaluation of players' winning-ness or losing-ness during gaming, and helping to describe attitudes of players and observers toward game entertainment (Iida et al. 2003; 2008; 2012a; 2012b). Since it has been seen that games are uniquely positioned to elicit such things as the great potential of computers, as well as the joy of victory and the agony of defeat, GRT is endeavouring to define every aspect of the game in order to develop a computational model with stronger, more general capabilities. For the time though, we will stay with the more discrete data environments, and extrapolate those findings to video games and sports later.

Early papers in GRT were based on the role of game complexity in the evolution of chess and chess-like games. The relationship of game complexity to uncertainty of game outcome was introduced as a measure of game entertainment (Iida, 2003). Game refinement theory then is based on the concept of uncertainty of game outcome. It is believed that the refinement of games' uncertainty is one of the quantities which has contributed to the success or extinction of games historically. Majek and Iida (2003) published a formal definition of game fairness. As with the developers of GT, Iida has taken notice that fairness is an important human factor in games (Iida, 2008). Because of the importance of Japanese games in GRT, sometimes Bushido, the samurai code of honor corresponding roughly to European chivalry, is cited for understanding of the roles of fairness, balance, entertainment, game dynamics, and for game creation (Ishitobi, Cincotti & Iida, 2012).

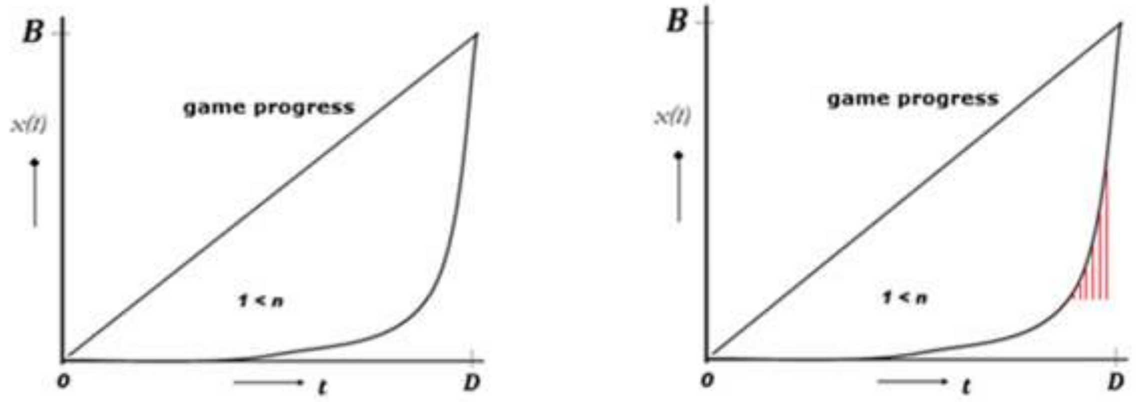
Fundamentally, games are comprised of information. It is the spontaneous composition of that information which provides the outcome. Iida, Takeshita and Yoshimura (2003) proposed the logistic model of game uncertainty. Majek (2004) and Iida, Takahara, Nagashima, Kajihara & Hashimoto (2004) defined the information of the game result as the amount of solved uncertainty $x(t)$, where the constant n is a parameter based on the difference of skill between the two players in the game, and $x(0) = 0$ and $x(D) = B$. Note that $0 \le t \le D$, $0 \le x(t) \le B$. The equation implies that the rate of increase in the solved information $x'(t)$ is proportional to $x(t)$ and inversely proportional to t. B is the branching factor while D is the functional, informatical game length expressing the size of the data set (not temporal game time).

$$x'(t) = \frac{n}{t} x(t) \tag{1}$$

Solving Equation (1) we get:

$$x(t) = B\left(\frac{t}{D}\right)^n \tag{2}$$

Shown graphically as the linear function "game progress" in Figure 3.a., below.



Figures 3.a. and 3.b. Logistic model of game-outcome uncertainty; and an area of interest under the game progress curve

When the information of the game is known (i.e., after the end of the game) and the value of *n* is 1 then the game progress curve appears as a straight line. However, in most games, especially in competitive ones, much of the information is incomplete, the value of *n* cannot be assumed, and therefore game progress is a steep curve until its completion, with B, D, x(t) and t, just prior to game's end. Assume that the solved information *x(t)* is twice derivable at $t \in [0,D]$. The second derivative indicates the acceleration of the solved uncertainty along game progress. This would be the difference of the rate of acquired information during game progress.

$$x''(t) = \frac{B}{D^n} t^{n-2}\, n(n-1) \tag{3}$$

The variables B and D are interchangeable with G (goals) and T (tries) when the games under consideration are measurable in those terms, such as like in volleyball or basketball (Takeuchi, Ramadan, & Iida 2014). Also found in (Sutiono, Purwarianti & Iida 2014):

$$x(t) = G\left(\frac{t}{T}\right)^n \tag{4}$$

and

$$x''(T) = \frac{Gn(n-1)}{T^n} t^{n-2} \tag{5}$$

that is to say,

$$\frac{G}{T^2}\, n(n-1) \tag{6}$$

It is known that players must self-evaluate during the course of games. It is believed that the acceleration of information at game end has a direct effect on the state of players (or observers). Game refinement theory hypothesizes that this is also a decisive measure of a game's entertainment, as evidenced by a close game, undecided until the very last move provides more tension and excitement than a blowout victory by one clearly superior side. Furthermore, it is presumed that the marked area under the curve in Figure 4.b. is an approximation of the informational CPG. This hypothesis can be strengthened by finding the information of gamers' experience, whether in terms of time, duration, or intensity. As Iida, Sutiono, Takeuchi and others have stated, there is a deficit of knowledge of the "physics of [information in] the mind." Work using fNIRS in games promises to widen that vista. A functional brain survey of the players to find the critical moment of cognition will be useful for understanding the time and the location in the brain that players are thinking or feeling about this impeding result in end games. Any experimental result identifying the area of brain activation at the CPG would certainly hold value for both disciplines.

It has been asked why anyone should bother with a new brain imaging experiment, when we could simply ask gamers "Did you feel excited at that time?" and such questions. Indeed, we will ask them, but few participants are capable of answering precisely which part of their brain was doing the work, or which stimuli might correlate to the changes in brain activation. It is hoped that brain imaging studies will shed some light on this question, and prove or disprove what we hypothesised about the reaction of gamers during game progress by elucidating a statistically significant brain oxygen pattern near game's end.

Brain Imaging

Neuroanatomy is a mature field where research has advanced to the finest details of the most microscopic and smaller levels of function and connectivity. The science of functional brain activity measurement is a sub-field still in its infancy where researchers are focused mainly on identifying the locations of neural activation under various cognitive stimulation. Advances in functional brain measurement are progressing and accumulating at a steady pace. Recently University of Washington researchers Rao and Stucco (2013) posted their experimental result online which purports to show the first instance of the use of a human brain-to-brain interface. Though some peers were understandably critical of their method of publication, Rao and Stucco proved the steady progress of functional imaging and showcased an interesting development with major implications for therapeutic use. See also Grau et al. (2014) for more advances in brain to brain interfaces.

Technologies like fMRI, positron emission tomography (PET) and x-ray computed tomography (CT or CAT scan) provide excellent spatial resolution and the ability to show oxygenation or metabolic processes in action, even deep within the basal structures of the brain—however the sensitivity and massive configuration of the hardware renders the subject immobile. So while those are superior qualities for medical purposes and research, fMRI, PET and CT present special challenges for research of people during normal activities. What fNIRS loses in terms of depth of measurement and spatial resolution, it makes up for with superior usability, mobility and safety to subjects and operators. At the time of this writing, scientists wanting to measure cortical blood-oxygen level dependent (BOLD) signal changes during any activity requiring more than facial, ocular or the most minimal of head movements need EEG or fNIRS. As Marco Ferrari and Valentina Quaresima have noted in the end of their review of the history of fNIRS for brain measurement that "Hitachi has introduced two battery operated wearable/wireless systems suitable for performing fNIRS measurements on adult PFC; i.e. a 22-channel in 2009 (WOT) and a 2-channel in 2011 (WOT 121B) (Atsumori et al. 2009 [in Ferrari & Quaresima]). Both instruments are currently only available in Japan" (Ferrari & Quaresima, 2012, p. 11). The Hitachi WOT-220® wireless fNIRS headset is shown in Figure 4 below. With temporal resolution of 5 Hz and analytical capability sufficient for producing cortical activation maps, measurements can be interpreted graphically, or with reference to an average brain (Figure 5).

Figure 4. Full mobility 22-channel fNIRS array (courtesy of Fujinami Laboratory, JAIST School of Knowledge Science)

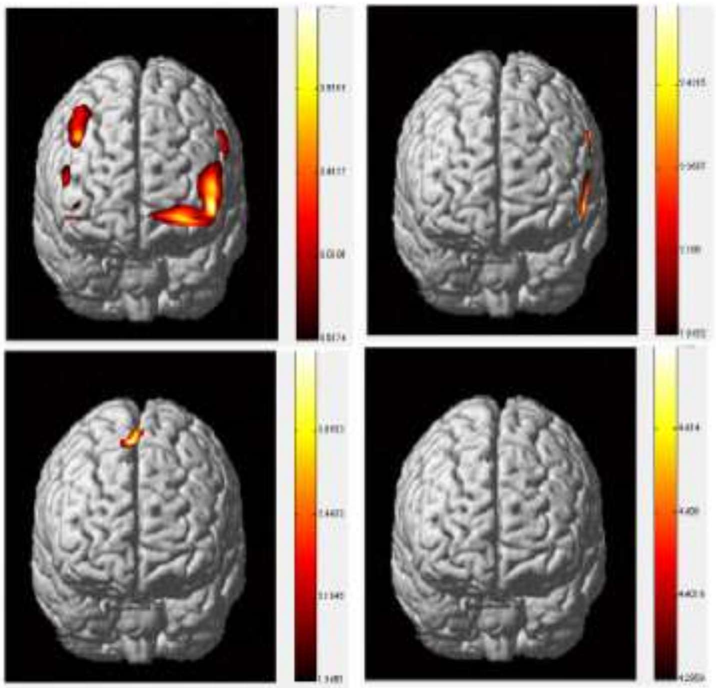


Figure 5. Images of fNIRS data on average brain (courtesy of Hideo Shinagawa, Institute of Social and Economic Research, Osaka University)

Frans Jobsis discovered that near infrared light could penetrate skin, bone and most tissues of the human body except haemoglobin, which absorbs some. Neurons, despite their large energy requirement, do not store oxygen and glucose. During activation neurons receive these from the blood. Neural activation causes increased flow of oxygenated blood to the active areas as well as increasing the flow of deoxygenated blood from the active areas, i.e. neuro-vascular coupling.

The development of fNIRS and functional magnetic resonance imaging (fMRI) for brain imaging are tied to the discovery of the BOLD signal in 1990. In that year, Seiji Ogawa and colleagues discovered that minute fluctuations in blood oxygen levels could be used to effectively measure, among other things, the functioning of the brain during MRI (Ogawa, Lee, Kay & Tank, 1990). Being able to detect the BOLD signal also forms the basis of fNIRS. Villringer and Chance recognized that “optical measurements could be performed in walking people or under other natural conditions that are not easily accessible by other functional methods” (1997). This consideration could prove crucial for cognitive experimentation.

fNIRS for Brain Activity Measurements in Gaming

Studies of players of recreational games with fNIRS began in the middle of the decade. Matsuda and Hiraki (2006) reported 21 five-minute long trials of 13 right-handed 7-14 year olds playing either one or both of two different video game types—a fighting type, and a puzzle type. They found decreasing oxyHb during the game in children, but had also reported the same in adults in their previous study referenced in the same work. Nagamitsu et al. (2006), responding to fears of the general public that video gaming could be detrimental to the human brain, performed nine trials on six children and six adults (three male, three female per group) during a hand-held video game. While Nagamitsu does not report any necessarily detrimental effects, the result adds to the body of evidence we seek to build for understanding the substrates of neural connectivity and interaction during games. They reported a possible age-dependent difference in the Hb oxygenation of the dorsolateral PFC (positive for adults, negative for children) which in hindsight also suggests a top-down modulation for the adult players but not for children.

In 2008, Audrey Girouard led a group of computer scientists and biomedical engineers from Tufts University to produce a ground breaking result in brain activity measurement of humans during gaming. They sought to prove, using a two-channel fNIRS device and the NASA Task Load Index, that researchers could determine whether a subject was at rest, playing an easy version of Pac-Man®, or a difficult version of Pac-Man®. They reported that indeed they could determine with 94% accuracy whether a player was resting or playing, and 61% accuracy whether the player was playing the difficult version or the easy version (Girouard et al., 2009). While this experiment was not the first brain measurement during gaming experiment ever, the attempt to measure differences in stress intensity of a player's experience using brain oxygen level dependent signals was largely successful. In some regards, it might seem like a very modest advance—using both user-reported and brain measurement data, with a wide margin of error it could be determined whether a person was playing the easiest, or the most difficult setting on Pac-Man®. Another way to look at this result however could be amazing: Using fNIRS technology, the Tufts group could, to an extent, measure how the player was feeling or thinking during a 30 second window, which signifies the earnest beginnings of measuring human mental experience. Using the improved fNIRS and other technology, such as EEG or heart/respiratory rates, with confirmation by self-reporting, it would be interesting to see how far that margin of error can be mitigated, and to see more and finer distinctions in functional brain measurement during activity.

Since the Girouard experiments, several more studies have been published in a similar direction. Hoshi et al. (2011) published results suggesting the possibility of recognizing emotional states, i.e. pleasant or unpleasant, using fNIRS. The work of identifying brain regions related to emotional responses using fNIRS is in its very beginnings, and seems to be gaining interest (Moghimi, Kushki, Guerguerian, & Chau, 2012; Doi, Nishitani, & Shinohara, et al. 2013; Kida & Shinohara, 2013). More recently Ono et al. (2014) conducted four trials each of 26 adults while playing a dance game "Dance Revolution," measured in the left side frontopolar cortex (FPC) and left middle temporal gyrus (MTG). Ono reported a remarkable separation of game (dance) performance in relationship to frontopolar oxyHb and sustained oxyHb in the middle temporal gyrus, with the lower performing players recording higher FPC, and lesser MTG activation, and high performers having decreased "suppressed" FPC and more persistent MTG activation, as evidenced by oxyHb.

BAMING

BAMING is the intersection of the physical world of brain measurement of gamers, and the informatical world of games and information. Development is growing along all axes, and the middle line (BAMING) has some new interest. The neuroscience side, with exciting new projects like the ambitious attempt to map the entirety of neural interconnectivity, the Human Connectome, is itself a cross-study of applied theoretical graph theory and neuro-anatomy (Hagmann et al., 2005; Sporns, Tononi & Koetter, 2005; Sporns, 2011). On the GT side of BAMING, Games-with-a-purpose, where players' inputs to an ostensibly recreational game are used for inputting to some other purpose of the game designer (Ahn & Dabbish, 2008) and serious gamers learn vital skills, e.g. in game simulations (Bellotti, et al. 2013). The building of brain-machine interfaces (BMIs) is an exciting new area of discovery, identified by Matthews et al. in 2008 as best served by fNIRS. At the same time most fNIRS researchers recognise that fNIRS is not yet a mainstream BMI technology, and has yet to be fully exploited (Matthews et al., 2008; Doi et al., 2013). Prior experiments in BAMING centred on economic gamers and recreational gamers in other contexts appear on parallel axes between the more theoretical line of this BAMING project, and the more applied science of brain activity measurement. The seemingly unanimous opinion of researchers in fNIRS and in gaming is that there is that there is a great need for more experiments in both fields. We recognize this to be an opportunity for rapid progress in the field of fNIRS for theoretical gaming.

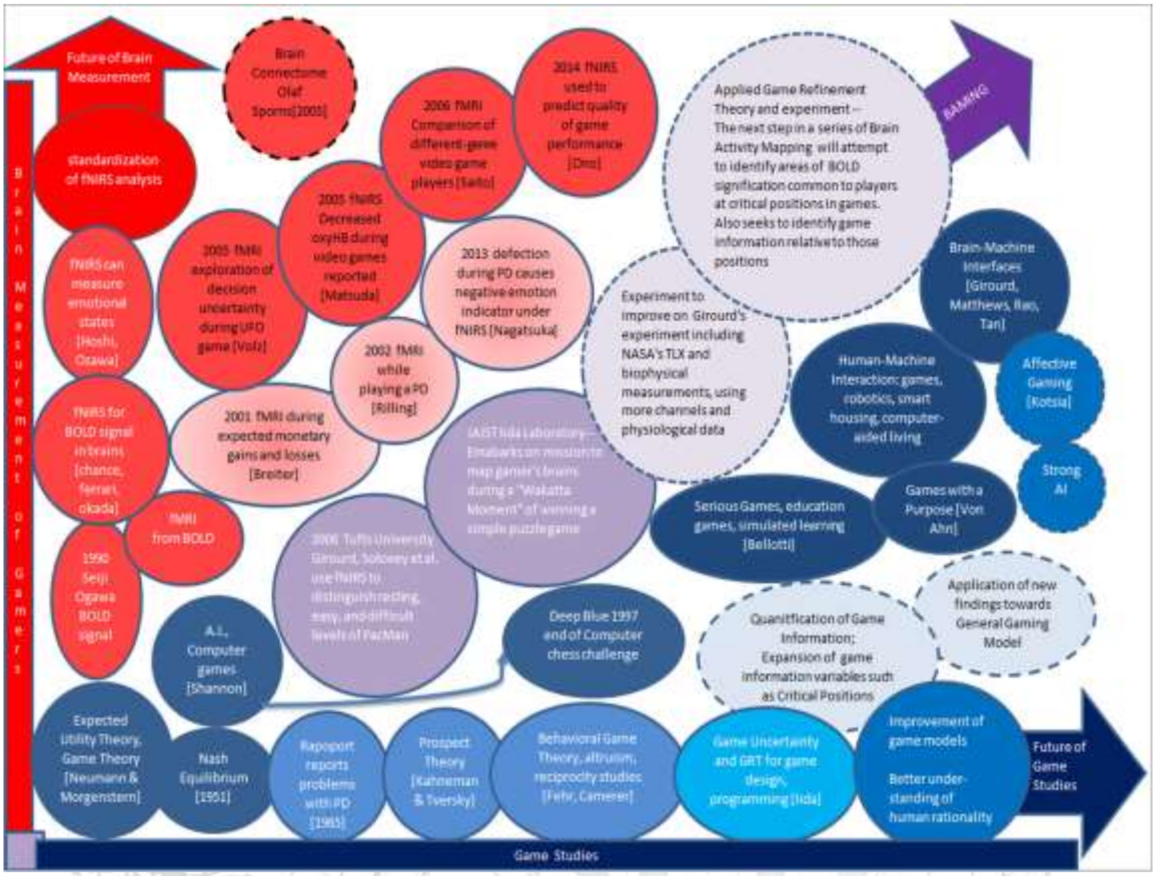


Figure 6. A research map of BAMING related fields. The y axis of Brain Measurement of Gamers is physical, while the x axis of Game Studies is theoretical. In between are some of the applications derived from or directly related to the two, including those currently under construction (dashed line) such as the Brain Connectome, affective gaming, strong A.I., and general gaming theory.

Our group also attempted a BAMING experiment designed to gauge our ability to measure, control and analyse fNIRS data for a player engaged in gaming. The experiment helped us to successfully identify the thing which we hoped to observe; a critical position in gaming, as well as several design and implementation challenges. We refer to that critical position as a Wakatta Moment, because of the Japanese word meaning "understood" or "got it." We used the Hitachi WOT-220® wearable infrared laser topography headset and associated hardware and software. For a game conducive to data collection we sought the game with the following characteristics:

-one player alone can play
-has a time limit for completion
-has an incentive for winning
-is fun or interesting to play
-has never been played by the subject

Eleven participants wore the headset for measurement of oxygenation/deoxygenation in their frontal cortices while they played a simple one-player puzzle game. The game included an imposed time constraint, and the promise of a modest prize if participants could solve the puzzle in time. All were expected to solve the puzzle during the experiment.

Once the information of winning (or losing) was presented, a neural response was expected to be discernable in the oxygenation record within a few seconds of stimulus. After analysing the data it was determined that non-uniformity of the time of stimulus over-complicated our analysis, ending in a null result (Nossal, Tsuchiyama, Iida & Hidaka, 2012). We also determined that ten out of the eleven participants did not realise they were close to solving the puzzle, and some were even unsure of having solved it even a few seconds after completion. Although conclusive fNIRS evidence of that Wakatta Moment was not immediately found in the first trial, we are confident that our first attempt at a BAMING experiment positions us (or a like-minded group of game or brain researchers) to implement a serious next attempt at substantiating the moment of recognition of winning/losing in the human player's brain..

Discussion

First, a new experiment should be done to replicate, verify and improve the result of Girouard et al., distinguishing the difficulty levels of play. Using mobile fNIRS along with heart rate, blood pressure, and video monitoring, it should be possible to match or exceed their 61% success rate for differentiating between high and low difficulty. The inclusion of an abbreviated form of the NASA-TLX or similar questionnaire could also be used to help interpret the results.

Secondly we propose a survey of 20 Japanese, or Japanese and American game players. The experimental vehicle will be able to isolate the particular moments and parameters of game progress, and the areas of the brain, and stimuli to be measured. A well-controlled game in terms of game progress such that the progression from opening to mid-game, end-game and win or lose is optimal, and could be achieved in a number of ways, such as with a PDAS or T-puzzle. Previous studies have used a timer to start and stop a continuous-play game. In our future experiments, we hope to elicit effects of winning or losing, along discrete sets of game information and time. A four or five-move game culminating in a decisive win or lose in the final step will be developed, and the rules clearly explained to participants shortly before testing. In the well-controlled time frame there will be a tolerance of less than 3 seconds deviation from the norm. It has been noted that 3 seconds is the approximate time required to convert neural responses to measurable oxygenation/deoxygenation patterns in the fNIRS medium. The information of winning or losing is the stimulus. Return to base should be expected within 30 seconds of the stimulus.

It has been noted that the PFC generally presents good measurability for "emotionally-charged tasks" (Strait & Scheutz 2014), such as the event of winning or losing a game. The 22 channel WOT-220® is presumed to be capable of measuring any of 22 channels extending in a semi-circle, roughly from the frontal to the temporal poles. The outer channels 1-4 and 19-22 often fail to record reliable data however, possibly due to the presence of hair, or gaps caused by the curvature of the headset over players' crania. In our experience without shaving participants' heads, the reliably measurable regions of the cranial surface are over the frontopolar (FP), orbital (O), ventrolateral (VL), dorsolateral (DL), and ventral anterior (VA) PFC. The VLPFC, the DLPFC, or the OFC are known regions relating to higher planning, decisions, rewards, and in the case of the OFC and VLPFC, inhibition of surprise, fear and sensory inputs (Hooker & Knight, 2012). Each of these regions could hold interest for the task, and additionally the superior frontal gyrus (SFG) has been identified in Connectomic studies as a hub of connectivity for the whole brain (Gong 2008). Using the wireless headset (in Figure 5), an upward adjustment of 4 centimetres on the average wearer's forhead permits a clear measurement of the SFG. Channels 6 and 18 are positioned to monitor the right and left VLPFC respectively, and channels 9 and 15 can monitor the OFC.

Conclusion

This paper identifies CPGs as a potential watershed for cognitive and game research. CPGs are the climactic moment in any game when a player acknowledges passing the failsafe point of win or lose. This principle, when proven, will have direct correlates to other non-gaming applications. We know that until just prior to the end of most games some uncertainty exists. There may, however, be a failsafe moment when the certainty of game outcome, in the shape of a steep upward curve, passes some reasonable point of no return. In terms of game information, when a player or observer recognizes which of the branches of the tree the game will terminate; the critical position has been passed. In cognitive or neurological terms, we can think of that as the Wakatta Moment. Our goal now is to concretely identify and measure that CPG by referencing the same moment in brain measurements using mobile wireless fNIRS, cross-referencing biophysical markers, and/or self-reporting.

We believe the goals stated in the previous paragraphs to entail an achievable and worthwhile pursuit for better understanding of both the dynamics of the game, and the actions and feelings of people during critical positions. It can be expected that a better understanding of game fundamentals will also enable modelling for general gaming computation. Research in games and cognition, and the science of functional brain measurement are a natural pair. While previous brain activity measurement studies of gamers have been done, this is the first we know of to offer brain activity measurement expressly for the study of games themselves, or for game refinement theory. As neuroimaging technology continues to improve, and game theory and game refinement theory grows, it can be expected that so will the scope of BAMING. Well-researched and computationally clear game science presents neuroscience researchers with great opportunities for meaningful experiments in human brain mapping and cognition. Both fields will continue seeing rapid improvements from this pairing.

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