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The Appraisal Equivalence Hypothesis:

Verifying the domain-independence of a computational model of emotion dynamics

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***Abstract*—Appraisal theory is the most influential theory within affective computing, and serves as the basis for several computational models of emotion. The theory makes strong claims of domain-independence: seemingly different situations, both within and across domains are claimed to produce the identical emotional responses if and only if they are appraised the same way. This article tests this claim, and the predictions of a computational model that embodies it, in two very different interactive games. The results extend prior empirical evidence for appraisal theory to situations where emotions unfold and change over time.**

Keywords—emotion modeling; appraisal theory; evaluation

I. INTRODUCTION

Appraisal theory is one of the more influential perspectives on emotion and arguably the most fruitful source for those interested in the design of intelligent systems, as it emphasizes and explains the connection between emotion and the symbolic reasoning processes. Indeed, the large majority of computational models of emotion stem from this tradition (for recent reviews, see [1, 2]). In appraisal theory, emotion arises from patterns of individual judgment concerning the relationship between events and an individual's beliefs, desires and intentions [3]. These judgments characterize the personal-significance events in terms of a fixed set of abstract criteria, called *appraisal variables,* and include considerations such as whether events are congruent with the individual's goals, are they expected and are they controllable. Patterns of appraisal trigger specific emotions. For example, a surprising and uncontrollable event might provoke fear. Although most appraisal theories (and models based on them) emphasize the immediate emotional reactions to events, emotions unfold and shift over longer periods of time and some theories (and models) posit that these changes are mediated by *coping strategies*—e.g., planning, procrastination or resignation—which modulate emotional responses through a continual cycle of appraisal and re-appraisal [3 p. 127, 4].

Appraisal theory, strictly interpreted, makes strong claims for how people organize their understanding and reactions to significant events. Appraisal theory can be seen as imposing a level of abstraction over the person-environment relationship, at least when it comes to emotion and emotion-driven reactions: the details of an emotion-evoking event are essentially irrelevant; what matters is how the event is appraised. A logical consequence of this strict interpretation is that two apparently quite different events must lead to identical emotions and identical cognitive responses *if and only if* they yield the same appraisals (allowing that different variants of appraisal theory may differ in their specific prediction as to what these appraisals, emotions and reactions will be). Viewed from this perspective, appraisal theory is analogous to decision theory, which argues that – with respect to making decisions – two decisions are equivalent if they have the same expected utility. Let us call this property of appraisal theories the *appraisal equivalence hypothesis*. Some phenomena, such as framing- or coping-effects (which also undermine classical utility theory) are reasons to suspect this hypothesis, motivating the present study.

The validity appraisal equivalence hypothesis has ramifications for the generality of appraisal theory and the models derived from it. The extent to which it is true will impact the accuracy of predictions that follow from the theory. It also has very important implications for artificial systems that aim to simulate or predict emotion, as it allows such systems to abstract away the details of a specific domain and thereby achieve a measure of domain-independence. For example, in some computational models of emotion (e.g., [5, 6]), appraisal variables are determined by domain independent abstract features of a situation, an approach that greatly simplifies the application of such models across domains.

Our goal in this paper is to test empirically the appraisal equivalence hypothesis and its implementation in the EMA (standing for EMotion and Adaptation) computational model of emotion [5, 7]. We identify several predictions that follow from this hypothesis. We evaluate those predictions in human subject studies involving two quite different dynamically unfolding competitive games.

A key prediction concerns equivalence across experience. Specifically, the appraisal equivalence hypothesis argues that we can significantly alter the surface features of a situation without altering the emotion elicited, as long as the

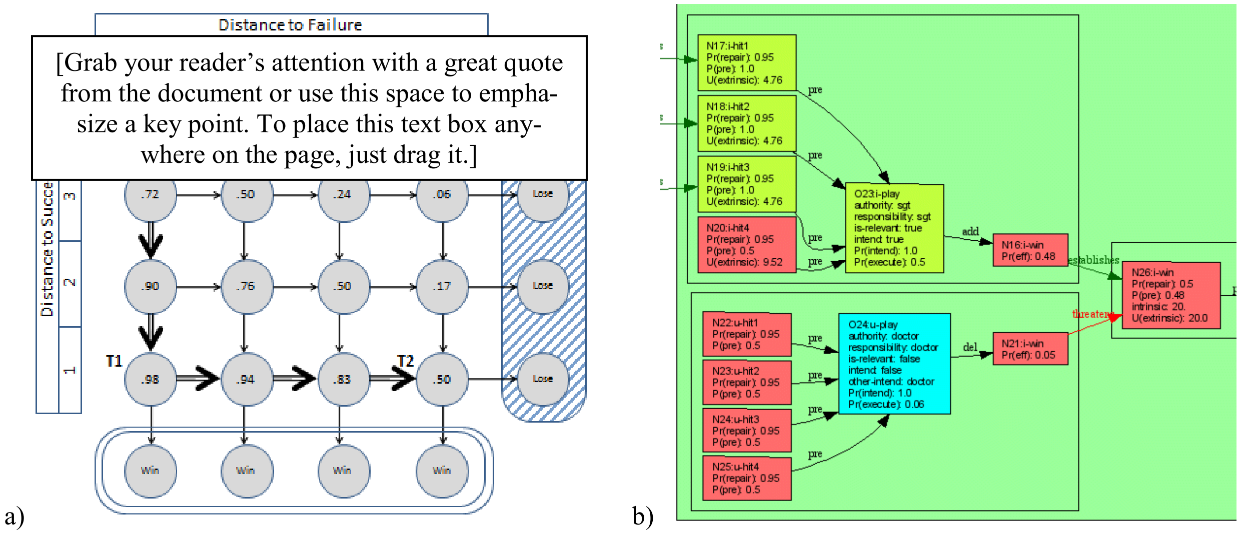


Fig. 1. A state space of a "coin flip" game (a) and the corresponding plan-space model of the same situation in EMA (b).

underlying structure of the situation (in terms of appraisal variables) is held constant. This hypothesis has been previously examined by appraisal theorists, typically using imaginary scenarios [8], though sometimes game-like settings [9, 10]. Games have the advantage that participants are actually experiencing the situation, rather than imagining what they feel. Many games also afford the opportunity to independently manipulate appraisals.

One novel contribution of this article over past empirical research on appraisal theory is that we explore the appraisal equivalence hypothesis using quite different competitive games – the Battleship board game by Milton Bradley and the MouseWars computer game [11] – that share a similar underlying causal structure.

Another novel contribution of this work is that we examine the dynamics of unfolding emotional situations and, specifically, how emotional reactions to momentary in-game events relate to overarching goals, such as winning the game.

Besides these general contributions to the study of appraisal theory, this article also investigates the more specific decisions that must be adopted when converting theory into a working computational system. One specific question relates to how sub-goals in a game gain their "affective charge" given that these intermediate objectives do not typically have intrinsic value, but are means to an end (i.e., they have extrinsic value). This question impacts the nature and magnitude of within-game emotions. For example, joy is normally considered a retrospective emotion, yet how can one experience joy within a game if rewards are only gained at the end? We test the mechanism proposed in EMA for how these intermediate states might produce emotions.

The results lend support to the concept of appraisal equivalence in dynamic situations, and the potential for automated techniques to generate valid emotional predictions, but they also reveal some subtle issues that must be resolved in future work. We discuss implications of these results for the design of computational systems that stimulate, simulate, and recognize human emotional experience.

II. Theoretical Claims

A. *Appraisal Equivalence Hypothesis*

The appraisal equivalence hypothesis implies a strong abstraction over situations. It asserts that two situations are identical from an emotional perspective, if and only if they share the same appraisals (that is, they are seen as equally desirable, expected, etc.), regardless of the surface details of the situation or the history of events leading to that situation. To illustrate this, consider following simple dynamic game wherein, through a series of discrete events, a player gradually moves towards and away from the goal of winning: players take turns flipping a coin and the first to reach four "heads" wins $100. Prospects of winning the money unfold over the rounds of the game: each flip has some local chance of making progress towards the goal (50%) but is set in the more global context of the previous sequence of flips. This is illustrated in Figure 1a, which shows the entire state space of this game, the probability of attaining the goal from each state, and one possible trajectory that a player might take through the state space. The appraisal equivalence hypothesis asserts that many of these 24 states may be identical in terms of how they are appraised and the emotions that result.

Let us consider the appraisal equivalence hypothesis in light of the trajectory illustrated in Figure 1a. The coin-flipping game begins at state T0 where, objectively, each player has an equal chance of winning. After taking an early lead (T1), the game returns to a point (T2) where each player has an equal chance to win the money. Many things are different between states T0 and T2: T0 is many steps away from winning, whereas T2 is one step away and there is a history if having recently squandered a lead, etc. From the appraisal equivalence perspective, however, the question boils down to whether these states have distinct appraisals.

In an objective sense, states T0 and T2 are identical: the probability of winning is the same; the payoff is the same; a player's control over the situation is equally limited by the fact that the coin has only a 50% chance of landing on heads. Yet in a subjective sense, they might be perceived as quite different. For example, the fact that the player was previously ahead may create a salient reference point that alters the emotional experience, or coping processes may have altered the perceived importance of wining (e.g., see [12]). To model this situation properly, we need to understand how people appraise, and how these appraisals might depart from objective reality, in dynamic unfolding situations.

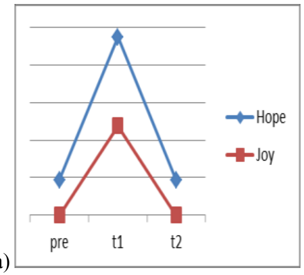
One way to test the appraisal equivalence hypothesis is to create states within an unfolding situation (e.g., T0 vs. T2), or across different domains that, at least objectively, should yield identical appraisals. For instance, if we could guide people through a specific trajectory in the coin-flipping game, we could systematically manipulate the probability of goal attainment. Alternatively, we could control for the importance people assign to goals (for example, distinguishing players that really want to win from those that do not). We might then predict that two players would feel the same emotions at T0 or T2, or if they differ, we would predict they must assign different value to winning.

B. Intrinsic and Extrisic Value

The scenario illustrated in Figure 1 has a dynamic and multi-leveled structure. The game unfolds over a series of rounds and local emotion-evoking events are embedded in a larger context. For instance, each individual coin flip can be seen as goal-congruent or goal-incongruent in of itself, depending on the result, but this result is likely interpreted in the larger context of how close the player is to winning or losing. We are not aware of empirical research on appraisal theory that examines the interplay between these local and global factors on emotional experience. Rather, empirical research validating the appraisal equivalence hypothesis has favored "one-shot" situation such as lotteries. For example, Reisenzein presents participants with a roulette wheel with monetary payout, and examines their behavioral and subjective emotions following each spin [13]). Other researchers have placed people in game like situations but only assessed the impact of local events [e.g., 9].

The coin-flipping game has a classic structure known in artificial intelligence as *delayed reinforcement.* In this structure, local events do not have value in of themselves, but only as a means to the end of winning. One way to describe this is that the end-goal has intrinsic value but intermediate sub-goals have extrinsic value (i.e., they are a means to an end). One obvious question in this context is how this intrinsic/extrinsic distinction impacts emotional experience? For example, consider the emotion of joy. Many appraisal theories [e.g., 14] characterize joy as a positive backward-looking emotion resulting from the achievement of a goal. However, would a person feel joy when their first flip lands heads? Or would they merely feel hope (a forward-looking emotion) that they will win?

Appraisal theories are silent on this distinction but computational models must resolve how intrinsic value impacts the emotions at intermediate states. The EMA model of emotion, for example, adopts a strategy analogous to

a) 

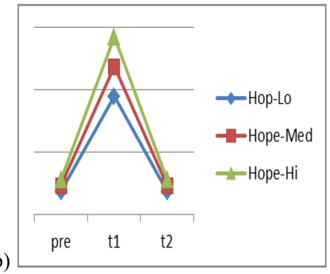
b) 

Fig 2. EMA predictions for the coin-flip game.

reinforcement learning and assigns sub-goals a value proportional to the extent they enhance the probability of attaining intrinsic goals [5].

C. EMA Predictions

EMA [4, 5] is a computational model of emotion based on the appraisal theory of Smith and Lazarus [15]. It derives predictions about how a situation will be appraised, and resulting emotions, by making inferences from the causal structure of a situation. Situations are represented as decision-theoretic plans, where specific actions have preconditions and probabilistic effects. For example, Figure 1b shows a plan-based representation in EMA that captures the sub-goal structure of the state-graph in Figure 1a. In this plan representation, there are two possible actions, each by a different causal actor, and each action has four sub-goals, corresponding to the four "heads" that each play must achieve. Different states in Figure 1a map to a particular number of preconditions in each of these actions. For example, the state T2 corresponds to the situation where each action in Figure 1b has three satisfied preconditions.

The EMA model of emotion embodies the appraisal equivalence hypothesis inherent in strong versions of appraisal theory, and incorporates the additional mechanism of extrinsic value to derive emotions associated with intermediate states. By running the model in Figure 1b, we can predict what emotions, according to the model, would be felt at states T0, T1, and T2. Figure 2a shows predicted intensity of felt hope and joy over these time points. Figure 2b shows how one emotion (hope) would change if individuals were to assign different levels of importance to the goal of winning.[1]

Several properties of these graphs are worth noting. First, both hope and joy increase from T0 to T1, and decrease from T1 to T2. For hope (a forward-looking emotion), this reflects the increased chance of winning the game. For joy (a backward-looking emotion), this reflects the extrinsic value of achieving sub-goals. Second, the intensity of emotion is identical in T0 and T2. This reflects the fact that the

[1] Given space limitations, we cannot describe the details of this simulation. One important point is that, for the purpose of these predictions, we disable EMA's use of coping strategies which may result in changes to goal-importance and goal-congruence as a function of the trajectory. This is due to fact that these coping strategies make qualitative changes but the model is under-constrained for making specific quantitative predictions. The research question below is aimed at resolving this deficiency.

probability of goal-attainment is identical in these two states. Third, intensity of emotion is proportional to goal importance as this factor is used in EMA's intensity calculations [16]. Finally, it should be noted that these predictions only depend on the causal structure of a domain and not the specific details of how this domain is instantiated. Thus, very different games should lead to the same emotion if the preserve the same underlying structure.

From this, we can derive specific predictions that we will test in the remainder of the article:

H1: The intensity of hope will increase from T0 to T1, and decrease from T1 to T2 (expected value hypothesis)

H2: The intensity of joy will increase from T0 to T1, and decrease from T1 to T2 (extrinsic value hypothesis)

H3: The intensity of hope will be equivalent at T0 and T2, as will the intensity of joy (within-situation appraisal equivalence hypothesis)

H4: The intensity of hope and joy will be positively correlated with final goal importance (intrinsic value hyp.)

H5: Hypotheses H1-H4 will hold for any domain that shares the same causal structure (between-domain appraisal equivalence hypothesis)

Finally, as noted in Section II.A, appraisal is a subjective process and may only imperfectly reflect the objective structure of the game. So, whereas the predictions in this section are driven by the objective structure of the game, hypotheses H3 and H5 may be invalidated, yet the appraisal equivalence hypothesis preserved, if we can show that states T0 and T2 are appraised in ways that differ from objective reality. This leads to the following research question:

RQ1: Are states T0 and T2 appraised equivalently within and between domains?

III. TEST OF OUR CLAIMS

We now test these hypotheses (and thereby assess the validity of EMA's predictions) by comparing human responses in two seemingly quite different games that share the same causal structure of the coin-flipping game.

A. Battleship

Battleship is a popular board game produced by Milton Bradley. The game is played with a plastic board and pegs (see Figure 3a). It consists of four 10x10 grids. Each player has a primary grid where they secretly place a number of plastic ships at the start of the game. The "tracking" grid represents the opponent's primary grid. Once the game starts, players take turns calling out locations on the "tracking" grid (e.g., "G-4"). The opponent must reveal if that location intersects with one of their ships ("It's a hit!") or not. When all cells on the ship are filled, it is announced as sunk ("you sank my battleship!"). The first player to sink all of his or her opponent's ships wins the game. The game is essentially a game of chance but players can exhibit some skill in their initial placement of ships and how they place their shots. Indeed, players often devote considerable mental effort to both of these decisions.

a)

b)

Fig 3. Battleship™ by Milton Bradley™ and MouseWars

Following the paradigm proposed in [16], we examine player emotional responses in a 4-ship, 9x9-grid game of battleship, which has an essentially equivalent structure to the game in Figure 1. There are 16 intermediate game states depending on the number of ships each player has sunk and two end states (win or lose). Each state can be characterized by the probability of winning from that point, and certain points (e.g., T0 and T2) are equivalent in this regard. As illustrated in Figure 1b, the game can be seen as consisting of a set of 4 sub-goals for each player, where each sub-goal has extrinsic value derived from the value each player associates with winning the game.

B. MouseWars

MouseWars is a web-based game developed by Gratch and colleagues [11] to study appraisals and facial expressions (see Figure 3b). Players take turns trying to get a mouse to move into their goal. The mouse (the icon in the upper-right of the central checkerboard) begins in the upper-left of the board. Players take turns spinning their own roulette wheel (the two circles seen in the upper corners of the interface). Each wheel contains a colored area that represents the probability that the mouse icon will move. If the wheel lands in the colored area, the mouse moves one square towards their goal. This is largely a game of chance, but players can exert effort to improve their chances. Each turn, a player gets 10 seconds to click a key as rapidly as possible and each click slightly increases the size of the colored area of the roulette wheel. Players often invest a considerable physical effort to move their mouse. From the perspective of appraisal theory, MouseWars is identical to the structure outlined in Figure 1. Each time the mouse moves, one of the players satisfies a sub-goal needed to win the game.

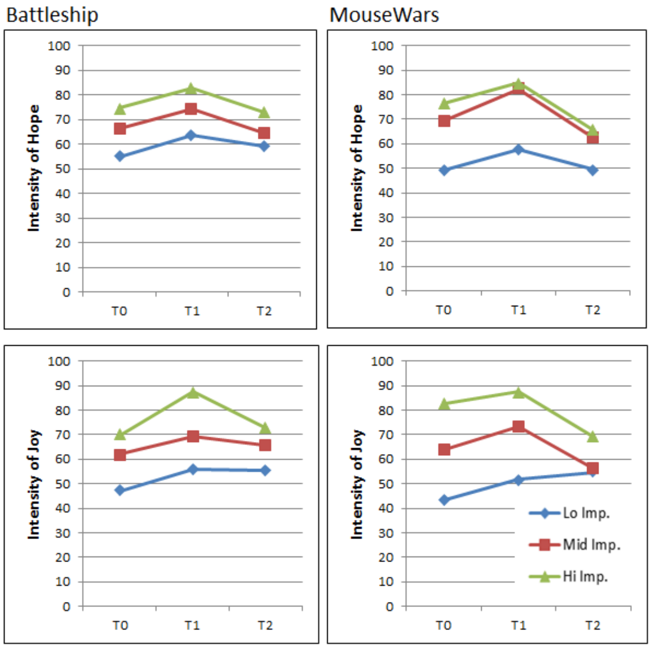


Fig. 4. Results of reported hope and joy for Battleship and MouseWars.

On the surface, the two games are quite different. Both games employ a grid to represent the game state, but the grids mean very different things: in MouseWars the grids visually represent the closeness to winning or losing but in Battleship this must be inferred from the configuration of pegs. Battleship involves physical objects whereas MouseWars is played on a computer. The task demands are also quite different. Battleship is more of a cognitive task, with players thinking hard about where to call shots. MouseWars is a physical task with players clicking hard to increase their chances each round. The games do share some attributes. Both are two person competitive games. In both games, the only incentive is the pleasure of winning (no financial incentives are used). Both games proceed by discrete turns and emotion questions are asked at similar points in during the game. Most importantly, from the perspective of appraisal theory, both games share the structure outlined in Figure 1.

C. *Experimental Design*

We use each game in a separate 2x2 mixed design. Following the paradigm introduced in [16], we use deception to manipulate, within-participants, goal-congruence (three levels: T0=pre-game; T1=highest peak; T2=the participant has fallen even with their opponent) by forcing them to follow the trajectory illustrated in Figure 1a. We manipulate appraisals of goal importance (three levels: low, medium and high), between participants, by querying participants *a priori* on the importance they assign to winning, and divide participants into tertiles based on their response.

In Battleship, 49 participants were recruited via Craigslist.com to play the game (56% male; mean age 32 years). Participants were led to believe they were playing a real game but, in fact, they played a confederate who secretly observed the participant's board and thereby delivered a pre-scripted sequence of hits and misses. Games lasted 31 rounds and followed the trajectory illustrated in Figure 1. In MouseWars, 78 participants were recruited from Craigslist.com (56% male; mean age 33 years). Participants believed they were playing a real game but, in fact, played a computer-controlled script: Each time the roulette wheel spun, it gave the appearance of a fair spin but the wheel was fixed. Games lasted 17 rounds and followed the trajectory illustrated in Figure 1.

In both games, play was halted at points T1 and T2 and participants self-reported the importance of winning, the probability of winning and the extent to which they felt hope and joy (all on a 100-point continuous scale). Participants were also asked these questions before the game starts (T0).

D. *Results*

Raw results are summarized in Figure 4. As a first step in testing hypotheses H1-H4, we ran ANOVAs on each game (Battleship and MouseWars) to compare reported level of emotion at the three time periods and the different level of *a priori* goal-importance. In Battleship, we found a main effect of goal-importance for both hope (*p*=.001, $\eta_p^2 = .275$) and joy (*p*=.000, $\eta_p^2 = .350$) and a main effect of time for both hope (*p*=.000, $\eta_p^2 = .351$) and joy (*p*=.003, $\eta_p^2 = .233$). In MouseWars, we found a main effect of goal-importance for joy (*p*=.007, $\eta_p^2 = .124$) and a near-significant trend for hope (*p*=.074, $\eta_p^2 = .067$). There was a significant main effect of time for both hope (*p*=.003, $\eta_p^2 = .074$) and joy (*p*=.002, $\eta_p^2 = .160$). There were no interactions between the factors, except in the case of joy in MouseWars (*p*=0.02) – *driven by the Low-importance group. The main effects of* goal-importance confirm hypothesis H4 (the intrinsic value hypothesis) for both games (see Figure 2b).

As the ANOVAs found a main effect of time for both domains, we further investigated H1-H3 (i.e., Figure 2a). For each emotion we performed pair-wise comparisons between T0 vs. T1 and T1 vs. T2 to test if emotions track changes in goal-congruence (H1, H2). We performed a pair-wise comparison between T0 vs. T2 to test if states with equivalent goal-congruence evoke equivalent emotions (H3). For Battleship, both hope and joy follow the hypothesized pattern: we found a significant increase in hope from T0 to T1 (μ=10.32, *p*=.004), a decrease from T1 to T2 (μ=-15.94, *p*=.000) and no significant change from T0 to T2 (μ=-5.61, *p*=.305); we found a near-significant increase in joy from T0 to T1 (μ=7.61, *p*=.052), a significant decrease from T1 to T2 (μ=-11.08, *p*=.003) and no significant change from T0 to T2 (μ=-3.47, *p*=.978). MouseWars also shows the hypothesized pattern: we found a significant increase in hope from T0 to T1 (μ=8.18, *p*=.012), a decrease from T1 to T2 (μ=-8.51, *p*=.009) and no significant change from T0 to T2 (μ=0.33, *p*=1.0); we found a significant increase in joy from T0 to T1 (μ=11.94, *p*=.001), a near significant decrease from T1 to T2 (μ=-7.39, *p*=.057) and no significant change from T0 to T2 (μ=4.55, *p*=0.563). Together, the results provide significant support for hypotheses H1 (the expected value hyp. for hope), H2 (extrinsic value hyp. for joy) and H3 (the within-situation appraisal equivalence hyp.) for both games.

With regard to the H5 (the between-domain appraisal equivalence hyp.), both domains show the identical pattern of results: hope and joy track goal-congruence and points with equivalent goal-congruence evoke emotions of the same intensity. Further, both domains show the same effect of goal-importance: individuals that assign greater importance to winning feel more intense emotions. Finally, the graphs in Figure 4 show striking similarity, not just in the qualitative changes verified above, but in the intensity of emotion at each time point. Together, these findings provide strong support for the domain invariance hypothesis.

E. Subjective Appraisals (RQ1)

The analysis so far examined objective factors, such as the probability of goal attainment, however appraisal theories argue that emotion arises from the subjective interpretation of situations., Previous work has illustrated that appraisals such as goal-congruence and goal-importance can shift within a situation via coping processes such as wishful thinking or resignation (e.g., see [12]). RQ1 examines how subjective appraisals relate to objective values and how they change via trajectory. Results are shown in Table 1.

A pair-wise comparison between T0 and T2 for each emotion shows that, unlike emotional experience, subjective appraisals significantly change as a function of trajectory in ways inconsistent with objective appraisals. In Battleship, both probability (p=.026) and winning-importance (p=.000) differ significantly. In MouseWars, importance differs significantly (p=.042) though probability does not (p=.127). Interestingly, these changes counteract each other (e.g., importance goes up but probability goes down), perhaps explaining why the self-reported emotions do not differ across these points.

We can draw several other conclusions from these results. First, subjective probability follows the correct pattern (people recognize that the chance of winning improves then diminishes) but the actual values depart considerably from the correct values: people are overconfident and show poor ability of to judge low probability events, consistent with prior research. Second, goal importance seems to increase throughout the game, even in the face of apparent looming failure that occurs from T1 to T2.

These findings suggest that cognitive and/or coping biases are in play, but that the magnitude of these changes are insufficient to undermine the appraisal equivalence hypothesis, at least in the context of these two games. More research is needed to understand how domain characteristics relate to these effects. For example, in these two games, the notion of being ahead or behind is transparent, leaving little room for wishful-thinking.

TABLE 1

Subjective Appraisals		MouseWars	Battleship
Probability	**T_0**	67	62
	T_1	79	79
	T_2	61	56
Importance	**T_0**	63	59
	T_1	66	72
	T_2	69	75

IV. Discussion

The article finds strong support for the appraisal equivalence hypothesis that underlies many appraisal theories, i.e., two situations are identical from an emotional perspective, if and only if they share the same appraisals. Participants played two quite different competitive games that shared the same underlying appraisal structure and reported remarkable similar patterns of appraisals and felt emotion over the course of the games. These findings provide further empirical support for appraisal theories and give novel insight in how appraisal changes in response to unfolding events. The results also have important implications for artificial systems that aim to simulate or predict emotion, as they give confidence that domain-independent models of such phenomena can be realized.

In future work, we plan to explore the relation between objective and subjective assessments more explicitly. One way to approach this is to manipulate it, for example by providing incentives such as money upon winning the game to manipulate intrinsic value or similarly money for achieving incremental sub-goals to manipulate extrinsic value. Such manipulations ideally will allow us to tease out the effects of coping. As important, we will need to move beyond appraisals of likelihood and desirability to extend the argument for appraisal equivalence to the full set of appraisal variables and eliminate simpler possible explanations based solely on probability and importance.

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