TOWARDS UNDERSTANDING THE INTERPLAY OF COGNITIVE DEMAND AND AROUSAL IN AUCTION BIDDING

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Research in Progress

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Abstract

IS perceptual constructs such as Arousal and Workload have shown to determine the impact of elements of user environment on their behaviour. While the impact of these constructs has been validated using a multitude of methods, there is little work which considers their dynamic interplay in determining behaviour. To this end, an auction setting where participants have shown differences in the first construct (arousal) due to auction dynamics is employed. We test whether the second construct (workload) is also observed under different auction complexities (dynamics and value uncertainty). By means of an experiment, we assess (i) frontal brain activity using EEG for workload, (ii) skin conductance response and heart rate for arousal, and (iii) bidders’ perceptions of workload and arousal using questionnaires. The first results show that high uncertainty and the introduction of a time pressure element leads to higher bids and higher deviations from Risk Neutral Nash Equilibrium (RNNE) strategy. In addition, subjects perceive higher workload under higher complexity, and this (concurs) with their workload index measured through EEG data. Further work will examine the interplay of arousal and workload, and whether only one construct plays a dominant role at a given point, or both act simultaneously.

Keywords: Arousal, Bidding, Cognitive Demand, EEG, NeuroIS.
1 Introduction

Online Auctions are being studied extensively, both from an auction theory perspective, understand
the price-making process, and from a design of information systems perspective, to better understand
user behaviour (Kamins et al., 2011). During the process of price formation considerable uncertainty is
involved, leading to conflicting utility functions for the buyer and the seller. Auctions hence provide
an environment where the primary task of the bidder is to estimate competitors’ expected valuations
and choose an optimal yet winning bid, a cognitively demanding task. From an IS design perspective,
understanding neural and decision-making processes are vital in determining both individual
behaviour as well as the overall auction outcome, and hence needs to be factored in as early as the
design and evaluation stage of these IT artefacts (Liapis and Chatterjee, 2011; Dimoka et al., 2010).
Specifically, cognitive and emotional processes are a key element of information systems in
determining user behaviour in contexts of incomplete information (including online shopping
websites, and consumer-supplier based systems). Auctions hence provide an interesting context for
studying the interplay between cognitive and emotional processes when individuals attempt to make
optimal decisions in a competitive environment (Van den Bos et al., 2013).

From the auction theory perspective, empirical experiments by Kagel (1989); Katok and Kwasnica
(2008) show that auction elements (such as time pressure, the level of uncertainty) have different
effects on arousal level of bidders, and determine their average bids, or how bidders deviate from Risk
Neutral Nash Equilibrium (RNNE) strategy. If cognitive processes were represented by cognitive
workload and emotional processes by arousal, we examine if subjects experience differences in these
two aspects due to differences in auction complexity. Based on the complexity, the competitive
environment of auctions necessitates a demanding level of both temporal and mental effort, especially
when estimating competitor’s bids, as well as in estimating uncertainty in calculating bidder’s rent.
Such demands have been often accompanied by physiological changes, in contexts such as road
driving (Mehler et al., 2009; Palinko et al., 2010), air traffic monitoring (Weiland et al., 2013) among
others, but not in the context of online auctions.

The goal of this research is to bridge the gap to determine how the IS constructs of Arousal and
Workload, interplay with each other, and determine bidding behaviour under auction complexity. We
investigate the following: (1) whether bidders perceive different levels of workload under different
auction complexities, (2) whether a physiological change is experienced when subjects perceive a high
level of workload under auction complexity and (3) whether a higher workload leads to lesser arousal,
and to what extent these IS constructs determine bidding behaviour.

To this end, we conduct an experiment in which users face auctions with different levels of auction
dynamics and value uncertainty. During the experiment, we assess (i) frontal brain activity by means
of an EEG as a proxy for their current level of workload, (ii) skin conductance response (SCR) and
heart rate (HR) as a proxy for their current level of arousal, and (iii) the bidders’ perceptions of
workload by means of questionnaires (Hart and Staveland, 1988). The paper presents preliminary
results of self-reported & measured differences in workload. Implications are discussed, and further
research agenda is detailed.

2 Theoretical Background

2.1 The Interplay of Cognitive Workload and Arousal

In the field of psychology, cognition and arousal are depicted as two de-coupled modes of thinking,
and referred to as dual-processing theories. While intuition is associative, holistic, automatic,
relatively undemanding of cognitive capacity and often emotionally charged, reasoning is rule-based,
analytic, controlled, demanding of cognitive capacity, and relatively slow (Kahneman, 2003; Lieberman, 2007). The theory argues that automatic processes (X-System or Reflexive System) are the background mode of brain functioning, so they are active most of the time. Only when automatic processes are interrupted (because of unexpected events or novel decision situations) do controlled processes (C-System or reflective systems) become active. Since the X-System is phylogenetically older than the C-system, automatic processes which are typically emotional in nature are hypothesized to affect human behaviour more than controlled processes do. Vom Brocke et al. (2013) take this theory and suggest that IS design science researchers should consider the direct influence of neural processes on user behaviour when building and evaluating IT artefacts.

The use of neurophysiological methods to assess cognitive load has been employed in previous IS studies. ECG (Hoover et al., 2012), EEG (Funke, 2013), ERP (Miller et al., 2011), Blood Pressure, Respiration, and Eye blinks (Veltman & Gaillard, 1998) have been employed as indicators of measuring mental workload and determining task performance as well. In the current study, we employ EEG as the measure of workload, as (1) workload index can be readily computed using EEG (Pope et al., 1995), (2) attention can be distinguished from related states, such as sleep, meditation, etc. by examining the spectral power in the respective frequency bands (3) such an index can also be computed and integrated as biofeedback into a decision support tool, analogous to (Astor et al., forthcoming). For arousal, we employ the well-established measures of phasic decrease in heart rate, and changes in tonic skin conductance response, in studies such as Adam et al. (2013), Sokol-Hessner et al. (2009).

Turning to the interplay of cognitive demand with arousal, Mauri et al. (2011) use physiological measurements like SCR, blood volume pulse and respiratory activity to examine if the experience of using the social networking site Facebook is associated with a specific psychophysiological state that might help explain the heavy success of social networking sites. Here, it is shown that during a cognitively demanding test there is an increased activation of the sympathetic branch of the autonomic nervous system, combined with the highest SC values, the highest beta waves activity, and deep breathing reflected by the longest respiration period. Mehler et al. (2009) show in a simulated driving environment, that with an increasing cognitive demand, elevations in skin conductance rate and respiration were observed, as well as a significant drop in driving performance. Rose and Fogg (1993) further show in an air-traffic controller context, a significant increase of behavioural arousal with increasing workload. Response in one physiological/behavioural domain was essentially independent of response in another, supporting the conclusion of specificity, rather than a global tendency to respond to increasing work load. While these studies point in the direction that both arousal and cognitive workload determine performance and behaviour, their interplay has not been studied in the context of online auctions. We hence focus on a setting where emotional arousal has shown to be observable in auctions under varied auction dynamics and uncertainty, serving as promising variables to observe this interplay and the degree of influence on bidding behaviour. The theoretical background on auction dynamics and uncertainty is explained in the next section.

### 2.2 Auction Complexity

Auction complexity can be parameterized by several elements: the auction format itself, the number of bidders, the level of information available, the level of uncertainty involved, the valuation of the underlying good, the mode of bidding (open auctions, or online auctions with a click-to-win element). We restrain our focus on those elements, where differences in arousal or differences in workload have been observed earlier, namely the auction format (Dutch or First-price sealed-bid (FPSB)), and level of uncertainty involved.

In a Dutch auction, the first bid is always tantamount to the winning bid and its revelation immediately ends the sales-process. The FPSB auction, in contrast, requires from every participant to submit his bid in a sealed fashion. The auctioneer then assigns the object on sale to the highest bidder (McAfee and McMillan, 1985). Katok and Kwasnica (2008) compare Seller’s Revenue (SR) across different auction
formats, establishing that SR (fast Dutch) < SR (FPSB) < SR (slow Dutch). These studies, and others, have gone to show the non-isomorphic nature of auction formats. Several explanations have been provided for this non-equivalence, among these, Katok and Kwasnica (2008) explain this irrational behaviour with the “utility of suspense”. Assuming that a bidder does not only gain utility from winning the auction with a favourable bid but also from the suspense and arousing experiences during the auction, bidders might have an incentive to prolong a Dutch auction as long as possible and to take the risk of not winning the auction. Specifically in the case of Dutch auctions, the introduction of the real-time element has been attributed to the changes in bidding behaviour, characterized precisely by 3 parameters, namely, (i) the distance between starting price and highest possible value that might exist, (ii) the delay time between successive price decrements, and (iii) the price decrement by which the Dutch clock decreases the standing price per tick. Grether (1992) published substantial evidence, coining the Erroneous Bayesian Updating hypothesis to show that individuals frequently ignore arising information to determine optimal bid, which seems to particularly hold for dynamic auctions, leading to too low a bidding function. Adam et al. (2013) examine the effect of the real-time element a bidder experiences during a Dutch auction compared to the First Price Sealed Bid (FPSB) auction. During a FPSB auction, a bidder is not able to make any observations about his rival’s bidding behaviour whereas in a Dutch auction the “click-to-win” element causes a higher arousal and excitement. Ku et al. (2005) refer to the state of “competitive arousal”, in which bidders experience strong emotions due to the competitive nature of auctions which in return weaken their ability to think and act rationally. Hence the element of time pressure in an auction has been shown to be correlated with irrational behaviour, as well as higher levels of measured arousal.

Turning to the element of uncertainty, Kagel (1989) finds evidence that bidders fail to behave rationally in sealed-bid auctions. The study supports the concept of the winner’s curse as subjects consistently overbid for items and experience losses while winning the auctions. By varying the level of uncertainty in affiliated as well as independent value auctions, Kagel’s results show that only 10% of profit opportunities are realized, and that a sizable number of bids even exceed the private signal. Thus, the element of uncertainty plays a vital role in determining the extent to which participants have shown to overbid, and hence a possible indicator of the extent of rationality employed. These experiments show that auction elements (such as time pressure, the level of uncertainty) have different effects on bidders, especially in terms of deviations from RNNE strategy. In this study, we seek a neuro-scientific approach to understand the interplay of cognition and emotions, which lead to deviations in bidding behaviour under auction complexity. Our primary focus is whether they lead to differences in self-reported and measured workload and arousal, and serve as explanations for biased behaviour.

2.3 Research Model

Based on the dual processing theory (Kahneman, 2003), the findings of Kagel (1989) with respect to bidding behaviour and uncertainty, and the findings of Katok and Kwasnica (2008), Adam et al. (2013) with respect to auction format, arousal and bidding behaviour, Figure 1 depicts the proposed research model. In a user environment consisting of different types of auction complexity (namely the uncertainty, and time pressure), participants’ bidding behaviour is studied. The direct impact of auction complexity on bidding behaviour is represented by H1. As was highlighted in the literature review, it is likely that auction complexity has a direct influence on both the constructs (cognitive workload and arousal), and will be reflected in both the methods (self-reported, and measured). These direct effects are denoted by H2 and H3 in the model respectively. Further, we postulate that both IS constructs mediate the impact of auction complexity on bidding behaviour, denoted in the figure by the hypotheses H4 and H5. The final hypothesis is H6, which focuses on the interplay between cognitive workload and arousal, indicated by a dotted double directional path. Taken together, we aim to understand the direction of interplay between cognitive and emotional measures, as well as the overall influence of this interplay on bidding behaviour.
3 Experiment

3.1 Experimental Design

In order to examine the interplay of cognitive and emotional processes in bidding behaviour, we adopt a 2x2 within-subject design, a factorial design of 2 levels each for the 2 types of auction complexity. Subjects play a repeated trial scenario with two auction formats (First Price Sealed Bid, and Dutch auctions), and uncertainty with two error terms (3 Monetary Units (MU) or 12 MU). The complete flow is depicted in Figure 2. Each subject plays against 2 computer opponents. While subjects were informed that they were bidding with computer agents, the exact bidding strategy of the agents was not revealed. In FPSB Auctions, participants can enter their bids in units of 0.5 MU, and do not have any time limit on when the bid can be entered, whereas in the Dutch auction, there is a clock ticking downwards in units of 0.5 MU, at a clock speed of 0.5 seconds as well.

The auction is designed based on Kagel (1989)’s, and Kagel and Levin (2002)’s model. In each round, the true value (V) is drawn randomly from the range [15,100] MU and private signals (s_i) are drawn from (V-ε, V+ε), where ε denotes the error term. Bidders (computer and human) are provided their individually drawn private signal, and the error term that was used to determine the private signals in that round. The expected bidding strategy is based on the Risk Neutral Nash Equilibrium strategy (s_i - ε) defined in this work, and computer opponents are programmed to place the RNNE bid. Overall bidding behaviour is examined in 40 auctions. The payoff was taken as the sum of a fixed amount of 20 Euros, and 5% of the cumulative earnings in all rounds. Since subjects bid based on the Private signal and Error Term information, indicating that the true value of the good is different in each round, this subtly enforces them to bid afresh in each round, avoiding the notion of ownership or a possible endowment effect. The study was conducted on 22 participants, consisting of 15 male and 7 female bidders.
3.2 Measures

The first measure consisted of self-reported scales used in IS literature to measure cognitive workload and arousal. The NASA TLX scale has been adapted to suit this context; to contain 5 relevant dimensions namely Mental Demand, Temporal Demand, Performance, Effort, and Frustration instead of the original 6. The dimension of “Physical demand” is omitted since it is not relevant for evaluating the auction task. The second method consists of psychophysiological measures of brain activity, HR, and SCR captured via sensors. For measurement of brain activity, a 32-channel EEG device of Brain Products was used, to record the electrical activity in the outer layer of the brain, namely the cerebral cortex. Signals were sampled at 500 Hz, band-pass filtered at 0.01 to 100 Hz, and checked for eye-blink artefacts. Power spectra were calculated from 2-second windows and across each treatment type, for 6 events of interest during the auction (Information Processing, Bid Click, Result Information, Regret Information, Payoff Information, and Next Click). The EEG Workload index mirrors the theoretical definition of cognitive workload, taking into account the absolute and relative power spectra from 1 to 40 Hz of EEG channel. The spectral powers of each of the frequency bands (Beta, Alpha, and Theta) are calculated on the Independent Components obtained from 14 frontal channels, and then workload is computed by the formula \( \frac{\text{Beta}}{\text{Alpha} + \text{Theta}} \) (Pope et al., 1995). For measurement of SCR and HR, Ag/AgCl electrodes were connected to the Biopix (2007) sensor system, and transmitted via Bluetooth. Participants’ risk aversion level was measured using the Holt & Laury Risk aversion questionnaire (Holt & Laury, 2002). This study has been conducted at the Karlsruhe Institute of Technology, in compliance with the university’s ethical guidelines, and following the recommendations of the Society for Psychological Research (SPR).

4 Preliminary Results

Across the participants, on an average, Dutch auctions resulted in higher bids than FPSB auctions. Figure 3 depicts the influence of the treatment variables on deviations from RNNE strategy, self-reported workload rating, and workload as measured by EEG.

Of the 22 participants, EEG data from 5 subjects was not complete either due to (1) errors in event synchronization or (2) lack of data from at least one channel required to compute the workload index, and was hence removed for testing all hypotheses. In order to test H1, we perform a fixed-effects GLS regression, accounting for within-subject fixed effects, revealing the significant effect of both treatment variables on bidding behaviour, with time pressure \( B=3.08, t=6.29, p<.001 \), and uncertainty level \( B=6.47, t=13.19, p<.001 \). This confirms in the current setting that the auction complexity determine bidding behaviour and deviations from RNNE strategy. Testing H2, the weighted workload rating (on a scale of 1-10) was regressed on the treatment variables. The means of
the 4 treatments are depicted in Figure 3, and the difference in means is confirmed by a GLS regression as shown in Table 1 (H2). Further, workload as measured by EEG activity (Beta/(Alpha+Theta)) was regressed upon the treatment variables, and was significantly different for uncertainty at the 10% level. This confirms that auction complexity impacts the perceived as well as measured workload.

Next, to test H3, the phasic decrease in heart rate was regressed upon the treatment variables, revealing a significant influence of both treatment variables (uncertainty, and time pressure), significant at 0.1% and 10% respectively. This result confirms that auction complexity influences the level of experienced arousal in the current setting. A preliminary test on H4 reveals that, for stimuli events, that measured workload does not have a direct influence on deviations from RNNE strategy. However, a Pearson test indicates a significant positive correlation between workload as measured by TLX and deviations from RNNE strategy. These results warrants further testing and can only be confirmed by completing the study on more participants with artefact-free data, as well as considering different epoch lengths for computing the workload index.

Testing H5 for stimuli events points in the direction that a higher heart rate corresponds to lesser deviations from RNNE strategy (B= -0.413, p < 0.1). This result points in the direction that arousal corresponds to better decision making in terms of placing risk neutral bids. This has to be confirmed by considering skin conductance response data as well, and applying a larger sample size.

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>(H1) Deviations from RNNE Strategy</th>
<th>(H2) Cognitive Workload Weighted Rating (TLX)</th>
<th>(H2) Cognitive Workload index (EEG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>SE</td>
<td>p</td>
<td>B</td>
</tr>
<tr>
<td>Dummy: is_dutch_auction</td>
<td>3.08</td>
<td>.49</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Dummy: is_high_uncertainty</td>
<td>6.47</td>
<td>.49</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Constant</td>
<td>6.94</td>
<td>.42</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>N=76 ; R²=.57</td>
<td></td>
<td></td>
<td>N=76 ; R²=.18</td>
</tr>
</tbody>
</table>

1. 17 Subjects * 4 Treatments
2. 17 Subjects * 4 Treatments * 6 Events

Note. B = Raw coefficient. SE = Standard Error +p<.1; * p < .05; ** p < .01; *** p < .001

Table 1. Fixed effects GLS Regression of treatment variables on (i) Deviations from RNNE strategy (ii) Cognitive workload rating using TLX (iii) Cognitive Workload Index using EEG.
In addition to the hypotheses listed, in order to account for learning over time, the variable “Trial Id” was added to the regressions in Table 1. While the effect of learning on deviations from RNNE strategy was not significant, subjects experienced a higher level of workload with more trials ($B=0.06$, $p<0.05$), especially in stimuli events. Further, participants experienced lesser decreases in phasic heart rate with learning, in other words, were less emotionally aroused with more trials ($-0.021$, $p<0.001$).

Taking the preliminary results of H1-H5, as well as considering learning effects, arousal seems to play a more pronounced role in earlier rounds of bidding, whereas the effect of workload seems to be apparent towards the end of the experiment. Also, the impact of the IS construct “arousal” on decreasing the deviations from RNNE strategy is more evident in this sample size, than the impact of workload.

5 Conclusions and Further Research Roadmap

In this paper we presented a research model to delineate the interplay of cognitive and emotional processes in auction bidding. To this end, an experiment is detailed, and preliminary results on hypotheses are presented. The first results show that expectedly the treatment variables significantly explain bidding behaviour, with respect to how participants deviate from RNNE strategy. In addition, participants perceive differences in workload, depending on auction complexity, as specified by time pressure and uncertainty levels. On average, Dutch auctions resulted in higher average bids than FPSB auctions. However, this is contrary to previous findings (Katok and Kwasnica, 2008) where lower Dutch bids were explained on the basis of “utility of suspense.” The most possible explanation is that in the case of bidding against computers, subjects are less affected by elements of the auction as compared to human bidders. Also, a higher starting price (of 105 MU) could gradually diminish the utility of suspense, and hence participants bid sooner than expected, and deviate more in Dutch auctions. Finally, this could be explained by the common value setting, wherein the distribution function is already common knowledge (Kagel, 1989) whereas the Katok and Kwasnica study is based on an independent private value setting.

The preliminary results of the research model reveal that arousal has a more direct influence on the deviations in RNNE strategy, as compared to workload, especially in the earlier stages of decision making. This finding is in tune with the dual processing theory, that automatic processes are the background more, whereas controlled processes become more active in a novel, uncertain decision situation, wherein workload levels reflect the additional conscious effort expended by the bidder to achieve a certain level of performance. From an IS perspective, since affect plays a more dominant role on behaviour, it could be inferred that continuous use of an IT artefact may be attributed more to automatic processes than controlled. These further relate to questions of habit formation, enjoyment, and flow. Finally, user acceptance and Technology acceptance studies consider controlled processes (with conscious reporting). Our results imply that these methods are possibly relevant in novel or uncertain decision situations, while for repetitive use of an IT-artefact or long-term habits, affective influences would need to be considered.

This experiment was conducted on human bidders against computer agents, but definite differences might exist under the same settings when bidding against other humans. In the following session, synchronized EEG recording technology will thus be essential to compare these results between subjects. Further, component spectral powers with a window size of 2s was computed to determine the EEG Workload indices, however different window lengths at the specific stimulus and response events should be considered to compute the workload level as well. Finally, the result of this study goes to show that deviations from expected bidding behaviour could be explained by workload in different settings of auction complexity. These findings could be extrapolated from auction settings to other complex decision contexts with varied levels of user workload and arousal. By providing feedback to regulate the experienced workload and arousal levels, adaptive or empathetic information systems can be built as decision support tools, analogous to (Astor et al., forthcoming) for arousal.
6 References


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