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Adaptation-By-Proxy: Contagion Effect of Social Buffering in an Artificial Society

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Abstract

The “social buffering” phenomenon proposes that social support facilitates wellbeing by reducing stress in a number of different ways. While this phenomenon may benefit agents with social support from others, its potential effects on the wider social group are less clear. Using a biologically-inspired artificial life model, we have investigated how some of the hypothesised hormonal mechanisms that underpin the “social buffering” phenomenon affect the wellbeing and interactions of agents without social support across numerous social and physical contexts. We tested these effects in a small, rank-based society, with half of the agents endowed with numerous hormonal mechanisms associated with “social buffering”, and half without. Surprisingly, our results found that these “social buffering” mechanisms provided survival-related advantages to agents without social support across numerous conditions. We found that agents with socially-adaptive mechanisms themselves become a proxy for adaptation, and suggest that, in some (artificial) societies, “social buffering” may be a contagious phenomenon.

Introduction

For social species, the formation and maintenance of (affective) social bonds has been associated with significant improvements across numerous wellbeing measures, including longer lives, reduced incidence of disease (Holt-Lunstad et al., 2010), and reduced stress levels (Ditzen and Heinrichs, 2014); with the absence of (perceived) social support associated with the opposing effects (Barth et al., 2010). One hypothesis for this effect, termed the “social buffering” hypothesis of social support (Kikusui et al., 2006), proposes that social support attenuates some of the physiological and psychological responses to stress, both during, and in anticipation of, stressful events. The hormone oxytocin (OT) has been implicated as one key mediator between (affective) social support and these stress-regulating effects, potentially by acting as a neuromodulator on stress-related physiological (Kiyokawa and Hennessy, 2018) and behaviour systems (Nelson and Panksepp, 1998).

For artificial (simulated and physical) social agents, understanding mechanisms for social adaptation remains a key area of research: with recent work considering (interactions

with) the social environment for agent learning (Yonenoh et al., 2019), cooperation and evolutionary dynamics in simulated agents (Gomes et al., 2017; Pérez et al., 2017), behavioural adaptation for human-robot interactions (Hiolle et al., 2014; Cañamero and Lewis, 2016; Hieida et al., 2018; Tanevska et al., 2019) and adaptation of homeostatic models via (affective) social interactions (Bedia et al., 2019).

The socially-grounded regulation of a homeostatic model may also be achieved via “social allostasis” (Schulkin, 2011; Sterling, 2020), which proposes an anticipatory, predictive adaptation of the homeostatic (Ashby, 1954) mechanism by integrating internal, external and social information. This mechanism of social adaptation, likely potentiated by the “social buffering” phenomenon, proposes a biologically-inspired mechanism for long-term adaptation for artificial social agents.

However, while previous research into these socially-adaptive mechanisms (including “social buffering” effects) have generally reported performance improvements for (artificial) agents that have been endowed with them, less attention has been given to the potential effects on the wider society, and in particular on agents in those social groups who lack mechanisms of (social) adaptation. The work presented in this paper is motivated by this limitation, and builds on our initial investigation into the “social buffering” phenomenon in societies of artificial agents (Khan et al., 2020).

In this paper, we investigate how the stress-regulating “social buffering” effects of social support affect the wellbeing and social interactions of agents who do not have social support in a society. Given the evolutionary fitness advantages associated with (socially-mediated) adaptation (Sterling, 2020), we hypothesised that there would be no viability-related advantages experienced by agents without social support when other agents in the society benefited from their adaptive effects. We test our hypothesis in a small, rank-based society, with socially-supported agents endowed with either one or two of the hormonal, stress-regulating mechanisms associated with the “social buffering” phenomenon. Contrary to our prediction, we found

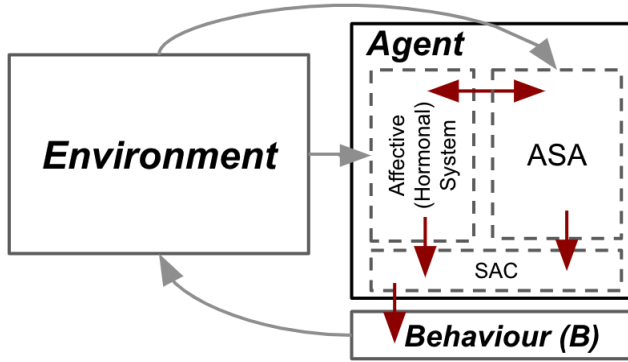


Figure 1: High-level view of the agent model used in this investigation and discussed in this section. ASA: Action-Selection Architecture (Eq. 1, Table 1). SAC: Social Assessment Component (Eq. 2). Additional details of the affective (hormonal) system are seen in Fig. 3.

that agents without social support experienced significant wellbeing improvements across numerous social and physical conditions, and these improvements were related to the type of stress-regulating mechanisms that socially-supported agents were endowed with.

Agent Model

Building on our previous work (Khan et al., 2020), our agent model comprises three main components: (1) a homeostatically-controlled Action-Selection Architecture (ASA), which selects behaviours to regulate two internal homeostatically-controlled variables; (2) the Social Assessment Component (SAC), which adapts agent behaviour based on appraisals of affective social relationships with others, and (3) an affective hormonal system which modulates certain aspects of agent “physiology” and behaviour.

Action-Selection Architecture

Using the long-standing approach from our research group (Cañamero, 1997; Lones et al., 2017; Lewis and Cañamero, 2019; Khan et al., 2019), the behaviours of our artificial agents are grounded in the regulation of a homeostatically-controlled internal “physiology” through the Action-Selection Architecture (ASA). The ASA selects actions to satisfy one of two physiological needs: *Energy* (a physical, survival-critical need) and *SocialNeed* (a non-critical need for social contact) (Table 1). Here, “critical” refers to a variable’s effect on agent survival: if *Energy* (but not *SocialNeed*) drops to its lowest value (0), an agent fails to remain viable and “dies”. Therefore, the goal of this homeostatically-controlled model is to maintain stability by keeping these values as close to their ideal values (1) as possible through relevant action selection.

Internal Variable (v)	Energy	SocialNeed
γ_v	$0.003 \times 2(SP_t)$	0.003
Motivation (m)	Hungry (m_H)	Lonely (m_L)
Behaviour (b)	Eat (b_E)	Touch (b_T) (Groom, Aggression)
Stimuli (S)	Food	Agent
Phys. Effect A	$v: +0.003/\text{time step}$	OT: $+0.003 \times TI^*$ $v: 0.05 \times TI$
Phys. Effect i	-	OT: $+0.003 \times TI^*$ CT: $\pm 0.003 \times TI^{**}$

Table 1: Relationship between internal variables v , motivations m , behaviours b and stimuli S required for each behaviour. “Phys. Effect”: Physiological effects of behaviour B on actor (A) and recipient agent (i). OT: Oxytocin. CT: Cortisol. *: Only for agents with affective social bonds. **: Opposing effects based on behaviour: - if *Groom*, + if *Aggression*. *TI* (Tactile Intensity) and SP_t are discussed in the Agent Model section.

The ASA works as follows: At each time step, each of the two internal variables v experiences a loss (γ_v) at a contextual rate (Table 1). The ASA calculates the deficit (i.e. the error, d) of both internal variables as the difference between its ideal value D and its current value (v_t , Eq. 1b). The error value is combined with the perception of external cues c to calculate the “intensity” of each of the two motivational drives (m , Eq. 1c). The motivation returning the largest value (i.e. the most “urgent” motivation) is selected as the winning motivation M (Eq. 1c). In this model, each motivation is mapped onto one of two behaviours: *Eat* when *Hungry*, and *Touch* when *Lonely*). The model selects the behaviour B associated with the winning motivation M (Eq. 1e), with agents moving to a relevant resource to perform the behaviour. Therefore:

$$v_t = v_{t-1} - \gamma_v \quad (1a)$$

$$d_t = D - v_t \quad (1b)$$

$$m_t = d_t + (d_t \times c_i) \quad (1c)$$

$$M_t = \max(m_h, m_l) \quad (1d)$$

$$B_t = \max(b_E, b_T) \quad (1e)$$

Social Assessment Component

The Social Assessment Component adds a contextual layer to the execution of social interactions by accounting for an acting agent’s affective (hormonal) state, the social status (rank) of other agents, and (for bonded agents) the presence and quality of an existing affective bond. The SAC therefore dynamically adapts social behaviours based on a “trade-off” between these features to determine (a) whether to approach

or avoid a food resource, (b) which agent to perform social interaction (Touch) with when multiple options are available, and (c) whether to perform a socio-positive (*Groom*) or socio-negative (*Aggression*) interaction. Acting agents A assigns a value to each agent i it perceives (χ_i , between -1 to +3) as follows:

$$\chi_i = \underbrace{\Delta K_{Ai}}_{\text{Relative Rank Difference}} + \underbrace{[\text{Bond}_{Ai} \times (\text{DSI}_{Ai} \times \text{OT}_A)]}_{\text{Affective Bond Status (Bonded Agents Only)}} \quad (2)$$

where $\text{Bond}_{(Ai)}$ is a boolean flag denoting whether a social bond exists between agents A and i (1 if bond exists, else 0), DSI_{AB} is the measure of affective quality of the social bond (between 0–2), and OT is a hormone oxytocin as we describe in the next section. As this investigation is focused on agents without affective social bonds, we summarise the SAC here, and refer to (Khan et al., 2020) for more detail.

In the absence of affective social bonds, χ_i is calculated simply as the difference in social rank between acting agent A and i , normalised between -1 and 1: $\chi_i = \Delta K_{Ai} = K_A - K_i$. A negative value indicates that Agent i is higher-ranked, and vice-versa. This value is used during the contextual execution of social behaviour, as seen in Figure 2.

(Affective) Hormonal System & Effects

Agents are endowed with either one or two biologically-inspired simulated hormones—cortisol (CT) and/or oxytocin (OT)—which act as modulators on agent physiology and behaviour in numerous ways. All agents are endowed with CT, but only agents with affective social bonds are endowed with OT.

In our model, **cortisol (CT)** is a stress-related hormone, released as a function of internal (physiological) and environmental (physical and social) stress, and has two modulatory effects.

CT’s first effect is that it modulates the default agent movement speed ($\text{Sp}_0 = 0.5$ units/time step), which depletes its *Energy* at a proportional rate (Table 1): the more CT in an agent’s system, the faster it moves, the faster the homeostatically-controlled *Energy* is depleted. Specifically, $\text{Sp}_t = \text{Sp}_0 \times (1 + (\text{CT}))$.

CT’s second effect is that it dynamically modulates the intensity of tactile interactions (T_{int}) being performed by acting agents. The intensity of tactile interaction adapts the rate at which the actor’s *SocialNeed* variable is satisfied (Table 1): the stronger the interaction, the greater the satisfaction of *SocialNeed*.

CT is either “secreted” (increased) or “inhibited” (reduced) at each time step, at a contextual rate (γ_{CT}); as a function of internal stress (the mean of physiological deficits, \bar{d}_i) offset by (available) external stimuli (*Agents* \hat{S}_A and *Food* \hat{S}_F):

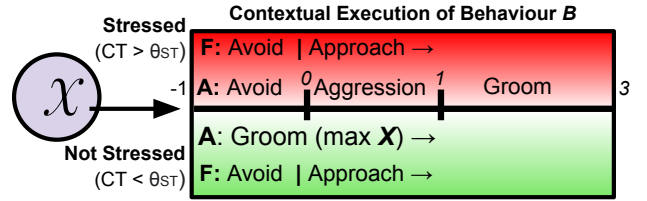


Figure 2: Illustration of the contextual execution of agent behaviours towards agents (A) and occupied food (F) resources, accounting for χ and an agent’s affective state. Numbers correspond to χ values calculated by Equation 2. Green denotes behaviours when agents are not stressed ($\text{CT} < \theta_{ST}$), red denotes behaviour when stressed ($\text{CT} > \theta_{ST}$).

$$\gamma_{\text{CT}} = \left(\underbrace{\bar{d}_i}_{\text{Internal Stress}} - \frac{1}{2} \underbrace{(\hat{S}_A + \hat{S}_F)}_{\text{External Stress}} \right) \times w \quad (3)$$

Here, “available” stimuli is calculated using the Social Assessment Component: where $\hat{S}_A = c_A \times (1 - \chi_i)$, $\hat{S}_F = 1$ when $\chi_i \geq 0$, else 0, and w is a scalar to regulate values. When agents *Groom*, CT is reduced by γ_{CT} in both the actor and recipient, but increased in the recipient during *Aggression* interactions (Table 1).

The second hormone, **oxytocin (OT)**, is a modulatory hormone associated with positive social interactions (Quintana and Guastella, 2020). In this model, OT is only present in agents with affective social bonds and directly regulates stress through either one or two mechanisms: by increasing the valence of social bond partners for social interactions (Eq. 2, Fig. 3, blue line), thus reducing the stress associated with the social environment (Eq. 3), and by modulating an agent’s internal tolerance to stress (CT) (Eq. 4, Fig. 3, red line). These mathematical models of OT effects are abstractions of two hypothesised mechanisms that underpin “social buffering” (Kikusui et al., 2006; Cohen and Wills, 1985).

Agents have an internal **Stress Threshold** (θ_{ST} , between 0–1), which determines how much of the stress hormone (CT) it can withstand in its physiology before it becomes “stressed” and adapts (social) behaviours. Agents have an initial Stress Threshold ($\theta_{ST(d)} = 0.5$), and this remains unchanged for unbonded agents. For bonded agents, OT’s second effect is that it modulates this internal stress threshold:

$$\theta_{ST} = \theta_{ST(d)} + (0.5 \times \text{OT}) \quad (4)$$

For bonded agents, θ_{ST} is in the range 0.25–0.75. Figure 2 shows how the “stressed” state adapts social behaviours in agents, with increased likelihood towards socio-negative interactions.

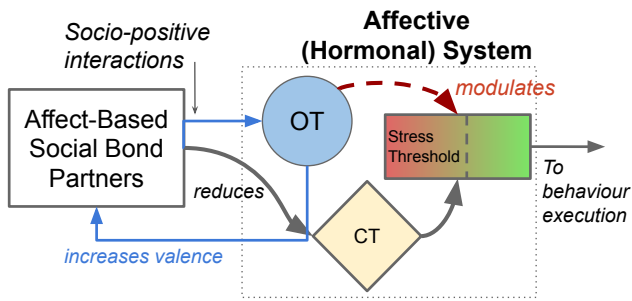


Figure 3: Illustration of the affective hormonal system used in our agent model. OT = Oxytocin. CT = Cortisol. “Social buffering” mechanisms are denoted by blue line (Type A models), and blue+red line (Type B models), as discussed in the Experiments and Results section.

Agent Perception & Behaviours

Agents randomly **wander** through the environment in the absence of perceiving a resource that satisfies (or changes) its current motivation, (Eq. 1c). Agents move at a default speed (0.5 units/time step), modulated by its current CT levels as described above.

To satisfy their *Hunger* motivation, agents perform the **Eat** behaviour by stopping to take “bites” of food resources, updating its *Energy* at a rate of 0.003 units/time step, until the motivation has been satisfied.

To satisfy their *Lonely* motivation, agents socially interact with other agents through the **Touch** behaviour. *Touch* encapsulates two sub-behaviours: socio-positive **Grooming** and socio-negative **Aggression**. Each of these behaviours have opposing effects on CT release in recipient agents (*Grooming* reduces CT in recipients, **Aggression** increases CT) at a contextual rate dependent on the intensity of tactile interaction (Table 1).

Experiments and Results

Our experiments were conducted using the NetLogo platform, version 5.3.1 (Wilensky, 1999). Our simulation model consisted of a small rank-based society comprised of six artificial agents, each occupying a different social rank (from 1 to 6), and endowed with the agent model described in the Agent Model section. This model and the dataset from this investigation is available online (Khan, 2021).

Experiments were conducted using three parameters denoting (a) the number of stress-regulating mechanisms that bonded agents were endowed with; either one (Type A models) or two (Type B models) (b) the physical environment in terms of food availability (our physical parameter, Fig. 5), and (c) the combination of agents that shared an affective social bond in each condition (our social parameter, Fig. 4). The latter two parameters replicate the experimental paradigm from our previous investigation (Khan et al.,

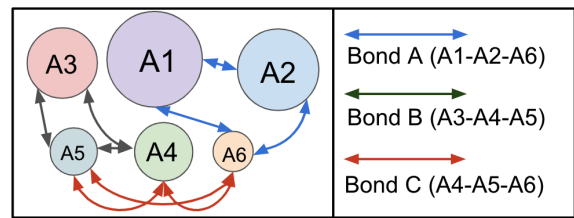


Figure 4: Illustration of the three bond combinations used in this investigation. Size and number correspond to agent rank (A1 is highest-ranked, A6 is lowest-ranked).

2020). We ran 20 simulations for each experimental condition, and each simulation ran for 15,000 time steps.

Model Types: Agents with social bonds were endowed with either one (Type A) or two (Type B) of the hypothesised mechanisms associated with the “social buffering” effects, mediated by our simulated OT. *Type A* models denote when OT modulated the valence of social bond partners, reducing the stress associated with the social environment (Equation 3, Fig. 3, blue arrow). *Type B* models included this effect as well as OT’s effects on modulating an agent’s internal Stress Threshold value (Equation 4, Fig. 3, red line). Agents without social bonds were not endowed with OT mechanisms in either condition.

World Conditions: Experiments were conducted in three conditions related to increasing challenges of the physical environment (i.e. availability of food resources): Static (STA), with four fixed food resources, Seasonal (SEA), where food resources steadily decrease (4→1) and increase (1→4) every 1000 time steps in one-food increments, and Extreme (EXT) worlds, where food resources undergo an immediate change between 4 and 1 resources every 1000 time steps. Screenshots of these worlds are seen in Figure 5. **Social Bond Combinations:** In line with our previous study (Khan et al., 2020), we test three different combinations of agents that share an affective social bond (Fig. 4, i.e. **bonded** (B) agents). In each condition, 3/6 (50%) of the society were bonded, with three without social bonds (**unbonded**, (UB)). These are denoted as Bond A (where agents A1-A2-A6 are bonded) Bond B (A3-A4-A5 bonded), and Bond C (A4-A5-A6 bonded).

Taking the approach used previously in our group (Avila-Garcia and Cañamero, 2004), we measured results across three viability-related (Ashby, 1954) measures: Life Length (LL): the length of time an agent or group survives as a percentage of total simulation run time (from 0%–100%); *Mean Comfort* (MC): the mean value of the two homeostatically-controlled variables (between 0–1) across an agent’s life; and Physiological Balance (PB): the homogeneity of the satisfaction of these two internal variables (between 0–1).

Additionally, we report on mean CT levels and the distribution of social behaviours between agents. Quantitative re-

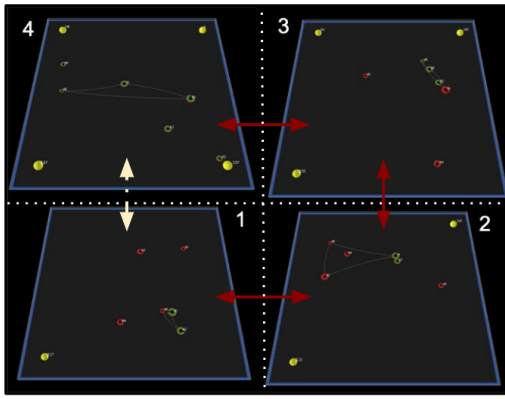


Figure 5: Screenshots of the three world conditions used in this investigation. Agents are doughnut-like shapes. Food resources are represented using yellow spheres. Top left: The *Static* world. Environmental changes are illustrated by red (for *Seasonal* worlds) and yellow (for *Extreme* worlds) arrows, and occur every 1000 time steps (starting at $t=2000$).

sults were complemented with qualitative reports where appropriate. Given the research question, results were primarily reported for unbonded agent groups, with results from bonded groups reported for comparison where necessary. Statistical significance testing was performed using one-way ANOVA testing, with significance declared at the .05 level.

Results: Viability Indicators

Control: As expected, in control groups, agent performance across all viability indicator metrics to be approximately correlated with the increasing world conditions (STA: LL=33%, MC=.65 PB=.75; SEA: LL=22%, MC=.55, PB=.49; EXT: LL=22%, MC=.53, PB=.51). Differences between environmental conditions were statistically significant at the .05 level for all metrics.

We observed a moderately-strong correlation between each of the viability indicators and an agent's rank ($r=$ LL=.57; MC=.68; PB=.79, $p < .05$ for all). In sum, an agent's viability was primarily associated with their social rank across all environments when no agents had social bonds.

Type A: Unbonded agents reported LL improvements across all experimental conditions, ranging from +2–46% improvements vs. control. In 2 of 9 experimental conditions (Bond C in STA and EXT conditions), unbonded agents reported greater improvements in LL vs. control compared to the improvements seen by bonded agents.

PB improvements for UB were seen across all-but-one condition (Bond A, EXT) vs. control, loosely corresponding to increasing physical challenge (STA: +2–4%; SEA: +2–6%, EXT: 0–12%), though this was significantly more modest in magnitude vs. bonded agent improvements (+8%–

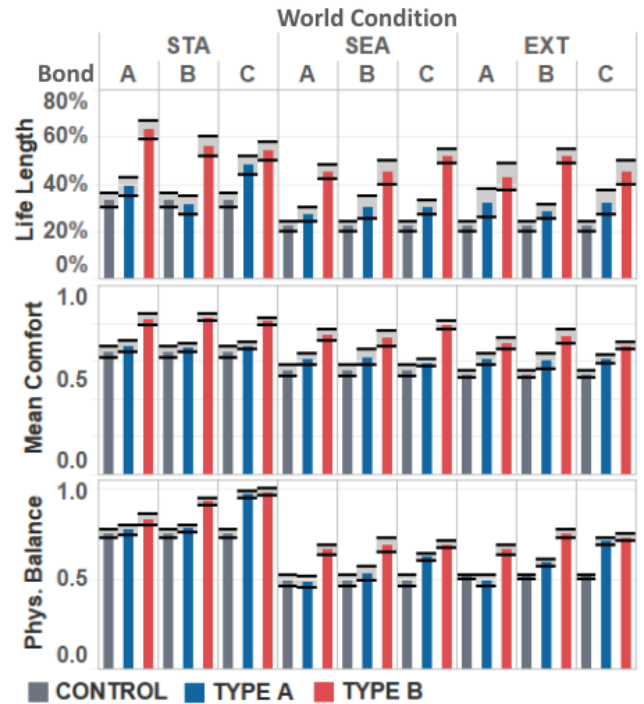


Figure 6: Results of the viability indicators for unbonded (UB) agents across all experimental conditions. STA = *Static* environments, SEA = *Seasonal*, EXT = *Extreme*. Black bars show standard error of mean values.

37%). However, in 4 of 9 instance, we found actual PB values to be comparable or greater in UB than B agents (STA, Bond C (.97 vs. .76); SEA, Bond B (.53 vs. .54); EXT, Bond B (.59 vs. .60), Bond C (.71 vs. .53).

Type B: UB agents reported significant improvements in mean LL vs. control, across all world conditions (STA: +70–75%, SEA: +89–104%, EXT: +92–104%). Unlike Type A conditions, UB agents reported significant improvements to MC across all conditions vs. control (STA: +19–20%, SEA: +17–26%, EXT: +12–24%). MC for UB agents was also significantly improvement vs. Type A conditions (+10–25%) across all world conditions. PB for UB agents saw significant improvements vs. both control (STA: +11–31%, SEA: +34–40%, EXT: +28–45%) and Type A groups (STA: +1–19%; SEA: +12–38%; EXT: +3–34%). Results vs. Type A conditions were statistically significant in all-but-two conditions (Bond C, STA and EXT).

In sum, UB agents saw significant improvements across all viability indicators when bonded agents were endowed with two stress-regulating mechanisms (Type B conditions), compared to groups with either no (Control) or one mechanism (Type A). Results were statistically significant across all conditions vs. control, with significant improvements seen vs. Type A groups in the majority of experimental conditions.

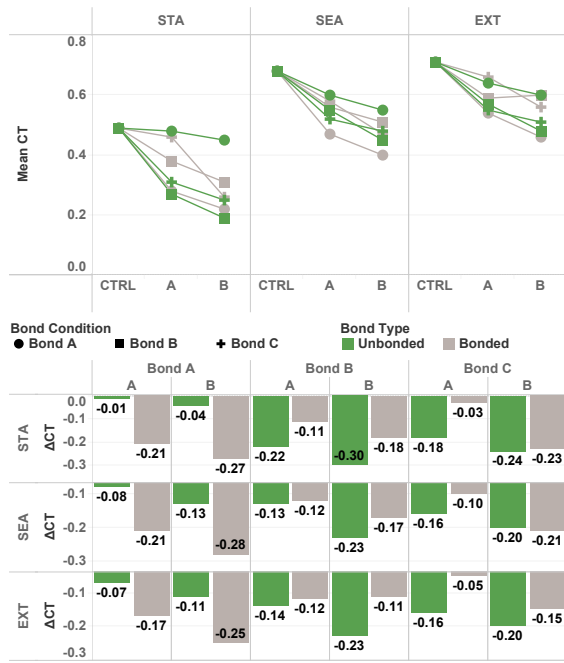


Figure 7: Top: Mean CT levels for unbonded (green) and bonded (grey) agents across all experimental conditions and model types. CTRL = Control. Bottom: Absolute difference in CT levels across conditions vs. control.

Results: Stress Levels

In control conditions, mean CT levels for the group were associated with the increasing physically-challenging world condition (STA=.49, SEA=.68, EXT=.71, Fig. 7) and were strongly-correlated with an agent's rank across all conditions ($r = .862$).

In both Type A and B conditions, UB agents experienced significantly lower levels of CT vs. control conditions across all world environments and bond combinations (Fig. 7). At an aggregated level, increases in CT levels for both UB agents were associated with the relative challenge of the physical environment (Fig. 7).

Compared to Type A groups, UB agents in Type B groups reported larger mean reductions in CT levels vs. control across all environmental and bond conditions (Fig. 7). Particularly in Bond Condition C for Type B agents, UB agents experienced similar reductions in CT levels as bonded agents, with non-significant differences between B and UB agent groups across all conditions.

In sum, both bonded and unbonded agents reported lower stress (CT) levels vs. control in both Type A and Type B conditions, with agents in Type B conditions reporting significant reductions in CT vs. Type A. Here, the magnitude of stress level reduction for UB agents (and the overall society) was associated with the number of stress-regulating mechanisms that socially-bonded agents were endowed with.

Results: Social Interactions

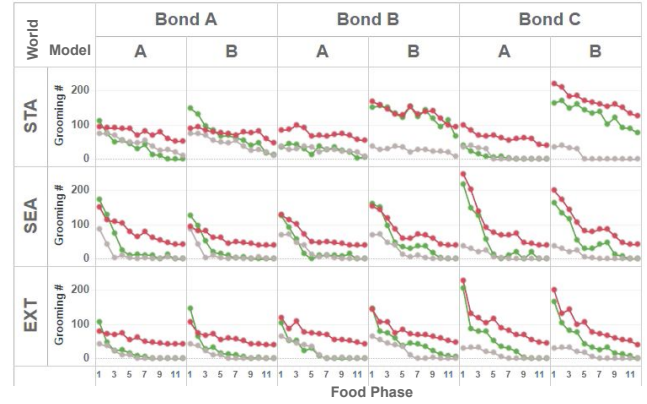


Figure 8: Trended amounts of socio-positive interactions (*Grooming*) for unbonded (green) and bonded (red) agents. Grey lines = control conditions for UB agents. STA = *Static*, SEA = *Seasonal*, EXT = *Extreme* world conditions.

Figure 8 shows the trends of socio-positive interactions for UB (green line), B (red line) agents, as well as control conditions (grey line) across all experimental conditions. Overall, we found a greater number of *Grooming* interactions from UB agents across all environmental conditions in Type B groups vs. Type A groups. Despite being lower in the absolute number of *Grooming* interactions, these socio-positive interactions followed similar trends to those of bonded agent in some experimental conditions in Type B groups (Bond B in STA, SEA; Bond C in STA, SEA, EXT).

Across all conditions, unbonded agents performed a significantly greater number of socio-positive (*Grooming*) interactions with other agents in both Type A (STA: 1,106, SEA: 1,421, EXT: 1,104) and Type B (STA: 3,909, SEA: 1,896, EXT: 1,600) conditions vs. control (STA: 771, SEA: 562, EXT: 520). These increases in *Grooming* were most notable in earlier phases, with 64% (STA), 57% (SEA), and 77% (EXT) of additional socio-positive interactions taking place within the first 5000 time steps.

We report a moderately-strong relationship between the total amount of *Grooming* by bonded agents and *Grooming* performed by unbonded agents ($r = .65$), with stronger correlations in Type B ($r = .71$) than Type A ($r = .61$) groups: suggesting a relationship between *Grooming* by bonded agents and *Grooming* by UB agents that is related to the adaptive mechanisms that bonded agents were endowed with.

In sum, societies trended towards more socio-positive interactions when half of the society had affective social bonds, with UB agents also performing more frequent socio-positive behaviours with other agents vs. control. UB agents in Type B groups performed more socio-positive interactions with others than Type A societies.

Discussion

Contrary to our hypotheses that “social buffering” would have no positive effects on unbonded agents (without social support), we found that these agents reported improved viability (Fig. 6), lower mean stress levels (Fig. 7) and increases in socio-positive interactions (Fig. 8) in conditions where the other half of the society shared affective social bonds. We found how these improvements in performance and stress-reduction in unbonded agents corresponded to the incremental socially-adaptive mechanisms that bonded agents were endowed with: from zero (control groups), one (Type A groups), and two (Type B groups) mechanisms respectively.

In this small society of artificial agents, the adaptive benefits associated with the “social buffering” phenomenon are not strictly restricted to agents with social bonds. Instead, the physiological adaptation and subsequent affect-based interactions between socially-bonded agents may also provide a wider, adaptive “buffering” for the wider social group.

Given that adaptation is a metabolically-costly process (McEwen and Wingfield, 2003), and that socially-adaptive mechanisms have evolved to provide viability (fitness-related) advantages for social agents (Sterling, 2020; Frank, 1998), our findings—that significant viability advantages are experienced by agents that have not been directly endowed with these mechanisms—are surprising. However, it also raises the possibility of an alternative type of “adaptation-by-proxy” mechanism for social agents in some (social and physical) conditions. From our results, we also suggest that this “adaptation-by-proxy” may be underpinned by some type of “affective contagion” related to the stress experienced by the wider society, which was driven by the affective interactions of socially-bonded agents.

Below, we present and discuss some further quantitative and qualitative analysis, and propose several mechanisms and interactions that may have played a causal role in these results.

Stress-Regulation, “Social Buffering” and Affective Contagion

In our post-hoc analysis, we found how bonded agents endowed with the Type B models (two stress-regulating mechanisms) trended towards more intra-bond socio-positive interactions vs. Type A models (Fig. 8): with lower mean intra-bond *Aggression* interactions (52% vs. 67%) and increased intra-bond *Grooming* (48% vs. 37%) rates as the additional “social buffering” mechanism was accounted for. Specifically, we found how accounting for a secondary mechanism of social buffering—the regulation of internal stress thresholds—for agents with social support permitted these agents to adapt their affect-based interactions towards more socio-positive behaviours, compared to models only accounting for one effect (Type A models).

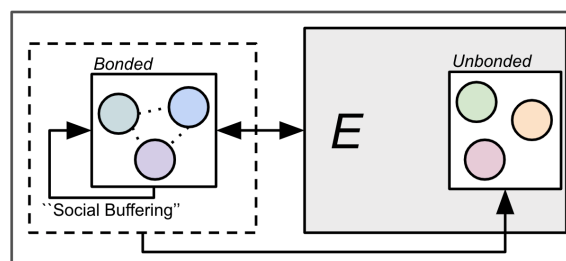


Figure 9: Bonded agents adapt physiology & behaviours via “social buffering” mechanisms: OT increases intra-bond socio-positive interactions; reducing CT, and adapts long-term stress tolerance which adapts future behaviours. More socio-positive (and less socio-negative) interactions, and reduced stress for bonded agents, reduces CT in unbonded agents, which facilitates their physiological and behavioural adaptation. Therefore, bonded agents become a mechanism of adaptation for unbonded agents.

This flexible behavioural adaptation, underpinned by socially-mediated physiological adaptation, had a clear pay-off for the wider society: higher rates of intra-bond *Grooming* between bonded agents lowers stress (CT), which (a) allowed them to not become “stressed” as world conditions became increasingly challenging (in SEA and EXT conditions) and (b) reduces the likelihood to perform socio-negative behaviours: either *Aggression* towards lower-ranked others, or avoidance of higher-ranked others) or time spent at food resources.

For unbonded agents, receiving less *Aggression* results in lower CT, and lower amounts of avoiding other agents (Fig. 2); increasing agent proximity and likelihood to *Groom*, further reducing CT levels in both the actor and recipient. Reductions in CT levels result in a lower *Energy* cost of movement (Table 1) and, while further investigation is necessary, we hypothesise that this “metabolic” adaptation (of speed and *Energy*) drove improvements in Mean Comfort and Physiological Balance in unbonded agents.

To summarise, we found a significant relationship between the (type of) physiological adaptation experienced by socially-bonded agents (the different types of “social buffering” mechanisms), their subsequent interactions with the social and physical environment, and the ability for unbonded agents to adapt to the (social and physical) environment; underpinned by (positive) affective contagion which played a causal role in improving the wellbeing of agents without social support. Though there may be additional behavioural dynamics to consider than those discussed, our findings nevertheless emphasise the importance of investigating micro (and meso-)level interactions between agents and the environments to understand emergent social dynamics; a point we have also made previously (Khan et al., 2020).

“Adaptation-by-Proxy”: An Alternative, Cost-Effective Mechanism of Social Adaptation?

In our artificial society, unbonded agents saw consistent viability-related benefits across several conditions, with increasing efficacy as bonded agents were further endowed with adaptive mechanisms (Type B vs. Type A models). Since bonded agents consistently outperformed unbonded agents across numerous viability-related metrics, the advantages in forming and maintaining social bonds are well-established in our experiments.

However, one surprising finding was how these socially-bonded agents—endowed with stress-regulating, socially-adaptive mechanisms—in turn became a “proxy” mechanism of adaptation for unbonded agents, as a result of the former’s physiological and behavioural flexibility as described above.

Considering the notion that stress (and therefore adaptation) has a metabolic cost (the “allostatic load” in the allostatic framework (McEwen and Wingfield, 2003)), the ability for agents without social support to experience viability improvements by exploiting the adaptive efforts of other agents may be considered a more (metabolically-)efficient mechanism for long-term adaptation.

These findings initially appear to be counter-intuitive from an evolutionary perspective, and raise an interesting question: if (some) viability advantages can be experienced by agents in a society, even in the absence of social bond formation (and its hypothesised, adaptive effects on physiology and behaviour), why would these mechanisms still evolve in those (social) agents?

One potential answer may lie in scenarios that we have not accounted for in our current experiments. For instance, the presence of a predator or competitor species, difficult physical conditions, or changes in climate may have provided a catalyst for the emergence of additional (affect-based) social behaviours; such as protection from physical harm (Dunbar, 2010), group foraging (Sutcliffe et al., 2012), or social thermoregulation (IJzerman et al., 2021), that may only be afforded to agents through affective bond formation or group membership. Though these are indeed areas for further investigation, the results from this experiment highlight how agents without social support can, in some social and physical contexts, benefit from the “social buffering” phenomenon.

Extrapolating these results, this may indicate that not all agents in a (small) artificial society would require the same (type of) adaptive mechanisms to experience viability benefits. For socially-affective, physically-embodied artificial agents (i.e. robots); our findings may have implications on the time and economical resources allocated to the development of their adaptive models, and researchers may consider these initial results when developing socially-adaptive models that may interact with other socially-adaptive agents. From a natural systems perspective, these results may point

towards an asynchronous or temporal evolutionary development of socially-adaptive mechanisms. For instance, in absence of competitive scenarios, the formation of social bonds (and its subsequent adaptive mechanisms) may not have developed simultaneously for social agents: but rather that some agents in a social group benefitted from the adaptive nature of others.

Future Work

Future work should investigate whether the viability benefits experienced by these unbonded agents, or the subsequent social dynamics, would extrapolate to larger social groups (including swarm-based societies); whether they are dependent on the ratio of bonded vs. unbonded agents (50:50 in our experiments), or the size of our physical environment. We propose that these initial findings can lay the groundwork for future investigations into these emergent effects, and, as we have done previously (Khan et al., 2020), emphasise the importance of analysing social dynamics at the micro and meso-level to better understand macro-level “emergent” phenomena.

Conclusion

In this paper, we have investigated how the “social buffering” phenomenon associated with social support affected the wellbeing and social interactions of social agents without social support across numerous dynamic environmental conditions. We hypothesised that social agents without social support would not experience any wellbeing benefits when other agents in the society could experience some of the “social buffering” effects of social support. Using a simulated model, we investigated this hypothesis in a small, rank-based society of artificial agents, where half of the society shared affective social bonds, and were endowed with either one or two of the hypothesised mechanisms underpinning “social buffering”. Our experiments tested these effects across numerous physical and social conditions. Contrary to our hypothesis, agents without social support reported significant wellbeing benefits across numerous social and physical environments. We suggest a type of “adaptation-by-proxy” for our artificial social agents; where agents with affective social bonds provided a mechanism for adaptation for unbonded agents, through the former’s physiological and behavioural adaptation: agents endowed with socially-adaptive mechanisms themselves become a mechanism for adaptation for other agents in the society. We suggest that “social buffering” may not simply be limited to agents with social support, but may be more of a contagious phenomenon that extends to the wider social group. Our findings may have practical implications in the future development of socially-affective, physically-embodied artificial agent models—where social(ly-affective) agents may not all require the (same type of) adaptive mechanisms to promote their viability or long-term adaptation of behaviours.

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