Scientific Reports

https://doi.org/10.1038/s41598-026-59260-w

Article in Press

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Received: 8 December 2025

Accepted: 19 June 2026

Published online: 02 July 2026

Cite this article as: Torres Borda L., Auer U., Kelemen Z. *et al.* Spatiotemporal dynamics of equine group formation reveal the gradual emergence of social cohesion. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-59260-w

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Spatiotemporal Dynamics of Equine Group Formation Reveal the Gradual Emergence of Social Cohesion

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Abstract

Stable social relationships are essential for horse welfare, yet domestic management often involves regrouping unfamiliar individuals, potentially causing social stress. Fine-scale dynamics of social integration remain poorly quantified due to limitations of observational sampling. Using ultra-wideband

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real-time positioning, we tracked the development of spatial and social relationships in two newly formed equine groups (n=19) over 2–12 months. Inter-individual distances decreased significantly, with time spent within 3m of conspecifics increasing from 1.2% to 27.3% within two months, demonstrating progressive spatial cohesion. Horses introduced with familiar companions integrated more rapidly than those introduced without familiar partners. Agonistic behaviour peaked initially and declined as stability emerged, yet occurred most frequently between closest associates, reflecting either active relationship negotiation or increased interaction opportunity from sustained proximity. No clinically relevant injuries occurred. Affiliative behaviours increased over time and were concentrated among preferred partners. Proximity to hay influenced social interactions, but its effects were context-dependent, varying with resource density, spacing opportunities, and group composition. Network structures initially showed centralisation near feeding areas, later transitioning to more even distribution. These high-resolution data reveal temporal trajectories of equine social integration and underscore welfare recommendations to minimise regrouping, introduce horses with familiar companions, and allow extended stabilisation periods.

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Introduction

Horses are highly social animals that, under unmanaged conditions, live in cohesive, stable groups, typically consisting of five to six individuals, organized around long-term associations.[1–10] These groups are maintained through enduring social bonds, with horses showing marked partner preferences that are strongly influenced by familiarity and homophily, such as similarities in age and sex.[4–17] Affiliative bonds are expressed and reinforced through proximity, synchronized activities, and mutual grooming.[4–17] These affiliative interactions, especially allogrooming, have been shown to reduce physiological and behavioural indicators of stress,

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including heart rate,[3,18–23] highlighting both their social and physiological significance. In contrast, lack of social contact is considered one of the most severe stressors for horses, leading to elevated faecal corticosterone metabolites and triggering stress-related behaviours and stereotypies such as weaving, cribbing, and box-walking.[1,9,14,24–30] Accordingly, opportunities for social interaction, especially the ability to engage in affiliative behaviours such as allogrooming, are widely recognised as fundamental ethological needs essential to equine welfare.[3,4,6,31–33]

Owing to their ability to recognize and remember individual conspecifics and to adjust behaviour based on prior interactions and social cues,[2,3,7,15,19,34–45] horses in stable groups with sufficient space and resources display few agonistic interactions, which are largely ritualized and involve little or no physical contact.[24,46–48]

However, domestic management practices often restrict horses' inherent sociality by housing them individually or grouping them according to human-imposed criteria such as age, sex, or use, thereby limiting their ability to select companions and form long-term bonds.[6,14,24,25,48–51] In addition, horses are frequently subjected to changes in herd composition, either through the introduction of unfamiliar individuals or the reshuffling of existing groups for seasonal, logistical, or management reasons.[6,14,24,25,48–51] Such regrouping disrupts social cohesion and elicits stress responses including heightened vigilance, increased locomotion and elevated aggression with correspondingly higher injury rates associated with repeated hierarchy renegotiation.[3,6,7,9,14,24,48,51,52] Persistent instability further delays the establishment of secure bonds, intensifies competition for resources, and contributes to chronic stress, with physiological consequences such as increased glucocorticoid levels.[3,6,7,9,14,24,48,51,52] Notably, horses do not readily adapt to regrouping, and stable hierarchies typically require 2–3 months to form,[14,51] underscoring the welfare risks posed by frequent social

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disruption. Taken together, regrouping represents a major welfare challenge in equine management.

Most prior research on grouping and regrouping has focused on overt outcomes such as the frequency of aggressive behaviours, bite and kick injuries, or feeding disruptions.[3,6,7,9,14,24,48,51,52] However, little is known about the fine-scale social dynamics that accompany this transition, including how affiliative associations and spatial relationships reorganize when new groups are formed, as traditional behavioural sampling methods provide limited resolution because continuous observation of group dynamics across days or weeks is rarely feasible. Yet, these dynamics are central to understanding the welfare implications of regrouping, because consistent social proximity and stable affiliative bonds are key markers of social integration. In this study, we use “social integration” to refer to the process by which newly grouped individuals progressively develop stable spatial associations and affiliative relationships, converging toward the cohesion and selectivity characteristic of long-established groups. This usage is consistent with the broader animal behaviour literature examining group fusion and immigration in social species, including primates and ungulates, where integration is operationalised through metrics such as proximity maintenance, affiliative contact, and reduction of agonistic interactions over time.[15,53–56] From an evolutionary perspective, the capacity to integrate following changes in group composition is likely adaptive, as group membership in free-ranging equids is not static, with natal dispersal, immigration, and the dissolution of existing bands necessitating the renegotiation and consolidation of social relationships.[6,38,57–59] Studying the trajectory of this process therefore has both direct applied relevance for domestic horse management and broader biological significance for understanding social plasticity in group-living mammals. Thus, in this study, we investigate new group formation, introducing previously unfamiliar or separately housed horses into new social units, and we employ ultra-

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wideband (UWB) sensor technology[46,60] to quantify how this process shapes spatial and social dynamics within shared environments. Specifically, we tested three hypotheses. First, drawing on evidence that inter-individual distances in newly formed groups of horses and other social mammals decrease over time as affiliative bonds develop and social relationships consolidate,[14,15,46,61,62] we hypothesized that inter-individual distances would decrease progressively, with initial fluctuation followed by stabilisation as social bonds consolidated. Second, based on the well-documented role of food resources as foci of agonistic competition in group-housed horses and other gregarious species,[24,48,63,64] we predicted that proximity to hay feeders would be positively associated with agonistic behaviour during early grouping phases, reflecting competitive exclusion at contested resources. Third, given evidence from both equine and non-equine species that prior familiarity reduces the costs of social negotiation and accelerates affiliation after regrouping,[15,22,65–67] we hypothesized that horses introduced with familiar companions would show faster social integration, characterised by reduced inter-individual distances and earlier increases in affiliative behaviour, compared to horses introduced without a familiar companion.

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Material and methods

Horses and Grouping Process

Group A comprised 15 mixed-breed horses (8 mares, 7 geldings) owned and housed by an equine sanctuary, aged 15–30 years (mean ± SD: 22.3 ± 5.2, Suppl. Table 1). Horses were maintained on a hay-based diet with ad libitum access to water. They were housed in a paddock (830 m2) with two hay feeders (2x2 m) providing 12 feeding places each and two indoor shelters (106m^2, 35.2 m^2) with straw bedding.

Group A was observed across five phases of new group formation, the introduction, integration, stabilisation, consolidation and follow-up phase

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(Suppl. Fig. 1). These phases should be interpreted as operational sampling intervals aligned with the grouping procedure, rather than discrete biologically defined stages. During the introduction phase, five familiar subgroups (dyads or triads) were sequentially added every three days until all 15 horses were housed together. “Familiar” individuals had been co-housed within the same stable social group for at least one year prior to regrouping, without major disruptive events such as regrouping or prolonged separation. We note that familiarity was defined operationally based on prior co-housing and does not imply quantification of relationship strength at the dyadic level prior to the study.

This was followed by an integration phase of 10 days, during which all 15 horses remained together (5 x 3 days, 15 days total). A stabilization phase (5 d) occurred subsequently, followed by a consolidation phase (11 d) two months later, when 11 horses remained after veterinary-based removals. A long-term stability follow-up (11 d) was recorded eight months after grouping, with 7 horses remaining.

Within Group A, horses were further categorised based on prior familiarity: A-Y (dyads introduced together; n = 18) and A-N (dyads introduced separately; n = 87). For veterinary reasons, two horses (Horses B and D) were housed overnight in individual box stalls (3.5 x 3 m) and only with the group for daily paddock turnout (6 h/day).

Group B consisted of four Franches-Montagnes stallions, owned by the Swiss National Stud and housed at the Swiss National Studs group housing site, aged 13–25 years (mean± SD: 18.5 years ± 5.2, Suppl. Table 1). Three stallions had prior group experience and one (Horse R) was naïve to group housing. All four stallions were introduced simultaneously and subsequently housed together on a 1-hectare pasture with ad libitum access to water, two hay feeders (2x2m) providing 12 feeding places each, and a shelter (4x20m) with straw bedding.

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Group B was observed across three grouping phases, the introduction phase (first 3 days), the integration phase (following 10 days) and the consolidation phase (4 days, 2 months later). One stallion (R) was temporarily removed from the group on day 1 of the introduction phase due to signs of stress-related colic. He was reintroduced within two hours without requiring veterinary treatment and showed no further symptoms thereafter.

Ultra-wideband (UWB) proximity measurements

Inter-individual distances were recorded using a ultra-wideband (UWB) real-time location system (RTLOC®, Ubisense) with a measurement range of 5 cm–100 m and accuracy of 32 cm (95% CI: 31–32 cm), which has previously been validated for equine behavioural research.[46,60] Lightweight sensors (8 × 7 × 2 cm, 95 g) were secured to the poll region of the horses' halters and worn continuously throughout each observation phase, with horses acclimatized to sensor-wearing prior to data collection. Absolute distances between all dyads were analysed while the horses were freely moving in their enclosure. Additional sensors were placed at the centre of each hay feeder to monitor resource access. Positions were recorded at 10 Hz and averaged to 1 Hz. A total of 760 hours of tracking data were collected (Group A: 615 h; Group B: 145 h).

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Data processing

Data were pre-processed according to established protocols.[46,60] Distance values exceeding the enclosure diagonal or below 5 cm were removed. The 5 cm limit reflects the physical minimum distance possible given that sensors are mounted between the horses' ears, as well as the measurement resolution of the UWB system. Periods in which distances remained unchanged for ≥10 s were treated as technical artefacts and excluded. Together, these cleaning procedures eliminated Group A = 19.7% and Group B = 29.1% of the raw data. Because each dyad (pair of horses) is recorded

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twice (distance between individual X and Y and distance between individual Y and X), these paired measurements were averaged to obtain one value per dyad.[60] We further excluded measurements involving one horse and a non-animated reference point (e.g., fixed tags on hay feeders or other environmental structures), retaining only horse-to-horse distances for analysis. Finally, due to technical issues in Group B, one entire tracking day had to be discarded (total observations used for analysis: Group A = 67,594,637; Group B =1,858,598). To differentiate feeding-related proximity from other contexts, a 3 m threshold was applied from the centre of each hay feeder. The 3m threshold from hay feeder centres was selected based on the physical reach of horses feeding at the 2×2 m feeder and established literature defining social proximity at ≤3 m.[4,5,31,68] Dyadic interactions in which both horses were within this distance were classified as “near the hay” (Group A = 40205516; Group B = 148726 measurements), whereas those where one or both individuals were beyond 3 m were classified as “away from the hay” (Group A = 52343250; Group B = 1709872 measurements). The 1 Hz high-resolution distance measurements were retained to capture fine-scale temporal dynamics, and analyses were performed on dyadic and phase-level summaries rather than on individual second-level observations, which are temporally autocorrelated and therefore not independent at the raw-observation level.

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Affiliation Categories: Closest Associates and Least Frequent Associates

The percentage of time two horses spent in proximity (≤ 3 m, a recognized cut-off for social proximity[60,68,69]) was calculated by dividing the total number of measurements recorded within each range by the total number of distance measurements (measurement frequency = 1 Hz). To evaluate the impact of social preference on proximity behaviour and agonistic interactions, the conspecific with whom each horse spent the most and least time within 3 m was identified as the closest associate and least frequent associate,[46,70] respectively. Because closest associates were defined by the

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greatest proportion of time spent within 3 m, this variable is derived from the proximity data and should be interpreted as a summary of preferential association rather than an independent measurement.

Because horses in group A were introduced sequentially in dyads and triads, the resulting pairings did not allow meaningful subdivision into subgroups A-Y (introduced together) and A-N (introduced separately), as in such small introduction units the same one or two individuals would simultaneously represent the closest associates, least frequent associates, and group average. Therefore, dyadic affiliation analyses were conducted at the overall group A level.

Behavioural event detection

Affiliative approaches and agonistic approaches, as well as high- and low-intensity retreats, were identified using previously validated algorithms described in detail elsewhere.[46,60] Briefly, events were defined by characteristic changes in interindividual distance, speed, and movement direction. Agonistic approaches were detected when two horses showed a directed decrease in distance of ≥1 m to <2 m within 3 s at a minimum approach speed of 85 cm/s, involving only a single dyad per event. High-intensity retreats were identified as corresponding increases in distance (≥1 m within 3 s) following an approach, whereas low-intensity retreats lacked the speed criterion. Affiliative approaches followed the same general spatial and directional parameters but occurred without subsequent retreat. Event rates were calculated per hour on both the dyadic and group levels and summarised by grouping phase and affiliation category (closest associates, least frequent associates, group average).

Allogrooming

Allogrooming was operationally defined as sustained dyadic proximity of ≤50 cm for ≥15 s, thresholds selected to capture head-to-head, or head-to-body

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contact typical of mutual grooming while excluding transient approaches. The 50 cm threshold approximates the spatial envelope required for horses to engage in reciprocal grooming, while the 15 s minimum duration excludes brief investigatory contacts. Algorithm performance was validated against video recordings for 10 randomly selected events (Suppl. Video 1) captured using a GoPro HERO4 camera (1280 × 960 px, 60 fps), synchronised to the sensor data via timestamps to enable frame-by-frame verification. Validation was performed by cross-checking a subset of randomly selected events against synchronised video recordings. While this approach confirmed correct classification for the validated events, the scale of the dataset precludes exhaustive estimation of false positive and false negative rates.

To reduce the likelihood of misclassification, conservative detection thresholds were applied, prioritising specificity over sensitivity. As a result, behavioural event frequencies reported here are likely to represent conservative estimates.

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Social Network analyses

To examine the social structure of each group, weighted social networks were constructed from dyadic spatial associations. For each dyad within each experimental period, an association index was calculated as the proportion of sampling intervals in which the two individuals were recorded within 300 cm of one another, a threshold used consistently throughout the study as an indicator of social proximity.

Networks were constructed using the igraph package (Csardi & Nepusz, 2006) and treated as undirected and weighted, with edge weights representing dyadic association strength (ranging from 0 to 1).

Three centrality metrics were calculated to characterise individual social positions: (1) node strength, defined as the sum of edge weights for each individual, reflecting total affiliative tendency; (2) betweenness centrality,

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quantifying the extent to which an individual lies on the shortest paths between all other pairs; and (3) closeness centrality, reflecting how directly connected an individual is to all others in the network. For shortest-path-based metrics (betweenness and closeness), edge weights were converted to path costs as 1 − association strength, such that strongly associated dyads incurred lower traversal costs. All centrality metrics were normalized to allow comparison across periods.

Activity Time Budgets

Time budgets for eating, resting, and activity were recorded throughout each observation period in group A using Hoofstep® wearable sensors (HoofStep Technologies Ltd., Cambridge, UK).[71,72] These devices integrate GPS, accelerometers, gyroscopes, and radio transmitters and were attached to each horse's forehead using a purpose-designed flexible softshell head collar. An embedded AI algorithm processed accelerometer and gyroscope data to classify behaviour into four categories: (1) *eating* (chewing, regardless of posture or concurrent behaviour), (2) *resting* (standing or lying without active movement), (3) *active* (slow locomotion such as walking), and (4) *highly active* (rapid movement such as trotting or cantering, including potential stress-related behaviour such as headshaking). Data are presented as the proportion of time spent in each behavioural category.

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Statistical analysis

Statistical analyses were performed in GraphPad Prism v.9.5.1. Distance and behavioural frequency data were tested for normality using the D'Agostino–Pearson test. Because assumptions of normality were violated, non-parametric tests (Kruskal–Wallis, Spearman's correlation) were used for univariate comparisons, while mixed-effects models were applied for multifactorial analyses.

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Data were analysed both at the dyadic and individual levels. Group-level dyadic analyses treated each pair as a single unit, whereas individual-level analyses included all interactions per horse, meaning dyadic events were represented twice (once per participant).

At the individual level, a repeated-measures Kruskal–Wallis test was applied to all horses pooled across both groups, with grouping phase as the repeated factor, followed by Dunn's post-hoc comparisons for pairwise phase contrasts. At the group level, mixed-effects models (restricted maximum likelihood (REML) estimation, Tukey post-hoc tests) assessed effects of phase, group, and affiliation category (closest associate, least frequent associate, group average) on proximity and behavioural metrics with individual horse as random effect. Spearman's rank correlations quantified associations among variables. The comparison between A-Y and A-N is an internal within-Group-A contrast isolating the effect of prior familiarity and is interpretively clean. The comparison between Group A and Group B is descriptive only, as the two groups differed in enclosure size, group size, sex composition, and management, and does not support causal inference regarding which factors drive observed differences between them.

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Network construction and extraction of network metrics were performed in R (version 4.3.2). The code used for these steps is provided as Supplementary Material (Supplementary Code 1).

Results

Interindividual distances

Inter-individual distances at the group level decreased progressively and significantly over time (grouping phase, $F(4, 2345) = 141.0$, $p<0.001$) and differed across groups ($F(2, 2345) = 148.0$, $p<0.001$, Fig. 1A, Table 1). Differences between all phases were significant for all groups (all $p < 0.001$).

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At the individual level, interindividual distances also differed significantly by group ($F(1,17) = 38.45$, $p < 0.001$ and decreased over grouping phases ($F(4,51) = 106.8$, $p < 0.001$, Fig. 2A). During the introduction phase, horses remained far apart (median: 1926 cm (95% CI: 1750 - 2997). Distances declined during the integration (1510 cm, 95% CI 1405 - 1652), stabilisation (1390 cm, 95% CI 1277 - 1431) and consolidation (1074 cm, 95% CI 915 - 1048) phase, reaching their lowest values in the follow-up phase (598 cm, 95% CI 520 - 607).

Affiliation category significantly influenced interindividual distances ($p < 0.001$), with closest associates being in greater proximity to each other (median: 334.1cm, 95% CI: 332.5 – 428.1cm) than both least frequent associates (median: 1481cm, 95% CI: 1244 – 1741cm) and the group average (median: 957.6cm, 95% CI: 896.4 – 1166cm, both $p < 0.001$, Fig. 3). Least frequent associates remained also non significantly further apart than the group average ($p = 0.157$, Table 2).

Proximity patterns differed also by distance to the hay feeder. Around the hay feeder, Groups B and A-Y (introduced together) rapidly converged to close inter-individual spacing from the integration phase onward and maintained tight clustering thereafter (Fig. 4A, Suppl. Table 2). Group A-N (introduced separately) remained the most dispersed until the follow-up phase, when proximity levels approached those of A-Y. Away from the feeder, a similar ordering emerged after the introduction phase with A-N remaining most dispersed, A-Y intermediate and B closest, although absolute distances were greater than around the feeder (Fig. 4B, Suppl. Table 3).

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Time spent in close proximity and affiliation category (closest and least frequent associates)

Analyses of time spent within 3 m of conspecifics revealed a pronounced increase in spatial affiliation as grouping progressed and consistent,

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selective association patterns (Fig. 1B, Table 1). Groups followed distinct trajectories over the study period with both group ($F(2, 2345) = 204.3$, $p<0.001$) and grouping phase ($F(4, 2345) = 88.63$, $p<0.001$) significantly influencing interindividual proximity. After the introduction phase, the smaller, all-stallion Group B maintained consistently higher proximity levels than Group A, which may be associated with both group size and sex composition. However, group A-Y closely paralleled group B's trajectory, whereas group A-N remained more spatially dispersed until the follow-up phase, when it too reached 34% time spent in proximity (Table 1).

At the individual level, time spent in close proximity also differed significantly between group ($F(1,17) = 15.43$, $p = 0.001$) and grouping phase ($F(4, 51) = 43.63$, $p < 0.001$) with significant differences between all phases (all $p < 0.01$) except integration versus stabilization ($p = 0.94$, Fig. 2B, Fig. 3A and B). During introduction, horses spent only 1.24% of total time in close proximity to a conspecific (median; 95% CI 0.73 – 2.25%). This proportion increased significantly across phases to 8.23% (95% CI 5.93 – 10%) in the integration, 12.13% (95% CI 10.11 – 14.07%) in the stabilisation, 27.32% (95% CI 25.54 – 31.03%) in the consolidation, and 35.5% (95% CI 31.39 – 39.94%) in the follow-up phase. Differences between all phases, except the integration and stabilization and the consolidation and follow-up phases, were statistically significant ($p < 0.001$).

Affiliation category significantly influenced dyadic time spent in close proximity ($p < 0.001$), with closest associates spending a significantly higher percentage of time together (median: 58.47%, 95% CI: 52.67% - 58.78%) than both least frequent associates (median: 9.17%, 95% CI: 6.9% – 13.69%) and the group average (median: 28.09%, 95% CI: 24.03% – 29.74%, both $p < 0.001$). Least frequent associates spent also significantly less time together than the group average ($p < 0.001$, data per phase: fig 3A and B, Table 2).

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Around the hay feeder, proximity increased steadily in group B, declined slightly during the integration and stabilization phases before rising again in group A-Y, and increased only during consolidation in group A-N, reaching levels comparable to the other groups at follow-up (Fig. 4C). Away from the hay, proximity decreased gradually in A-Y, increased slowly in A-N, and remained highest in B (Fig. 4D), yet overall values remained consistently lower than near the hay, highlighting context-dependent modulation of affiliative spacing (Suppl. Table 2 and 3).

Social Network analyses

Proximity-based social networks revealed context-dependent differences in spatial association structure (Figure 5, Suppl. Figure 3 and Suppl. Table 4). Across both groups, mean node strength was consistently higher near the hay area than away from hay, indicating increased spatial association in proximity to the resource.

In Group A, mean strength near hay ranged from 5.52 to 6.98 across experimental phases, compared to 0.46 to 1.30 away from hay. Strength near hay increased from introduction (5.53) to consolidation (6.98), while remaining low away from hay across all phases (1.30 at introduction, 0.46 at follow-up). In Group B, strength values were lower overall, ranging from 1.55 to 2.63 near hay and 0.83 to 1.20 away from hay.

Betweenness centrality was generally low across all networks. In Group A, mean betweenness near hay ranged from 0.03 to 0.12, and from 0 to 0.005 away from hay. In Group B, betweenness near hay ranged from 0.08 to 0.33, while away-from-hay values were 0 across all phases.

Closeness centrality showed higher variability across phases, with values in Group A ranging from 1.91 to 13.08 near hay and 1.05 to 1.10 away from hay. In Group B, closeness ranged from 2.82 to 8.95 near hay and from 1.41 to 1.83 away from hay.

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Overall, these results indicate that spatial proximity to the hay feeder consistently structured dyadic association strength, with stronger and more cohesive proximity networks in the feeding context, particularly in Group A.

Agonistic Behaviours

At the individual level, the frequency of agonistic approaches per dyad per hour differed significantly across both group ($F(1,17) = 58.21$, $p < 0.001$) and grouping phase ($F(4,51) = 8.41$, $p<0.001$). Agonistic approach rates peaked during integration and stabilisation, with some dyads exceeding six approaches per hour, while introduction, consolidation, and follow-up phases showed lower frequencies (Fig. 2C, Fig. 3 F, Tables 1, 2). Agonistic interactions were predominantly ritualized, and non-contact and no clinically relevant injuries ensued in any group at any time during the grouping process.

Affiliation category significantly influenced the number of agonistic approaches ($p < 0.001$), with closest associates (median: 1.47, 95% CI: 1.24 – 1.75 approaches/h) showing markedly higher rates than both least frequent associates (median: 0.235, 95% CI: 0.25 – 0.65 approaches/h, $p < 0.001$) and the group average (median: 0.686, 95% CI: 0.66 – 0.93 approaches/h, $p = 0.0031$, Fig. 3F). Least frequent associates displayed the lowest frequencies overall ($p < 0.005$). Correspondingly, the rates of agonistic and affiliative approaches were strongly correlated (Spearman's $r = 0.80$, $p < 0.001$), indicating that individuals who interacted more frequently in one context also did so in the other.

Similarly high and low intensity retreats were significantly influenced by affiliation ($p < 0.001$) with closest associates (both $p < 0.001$) and the group average (high intensity retreats: $p < 0.001$, low intensity retreats: $p < 0.005$) exhibiting significantly more retreats than least frequent associates (Table 2, Fig. 2F, Fig. 3. G and H).

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At the group level, agonistic approach frequency was also significantly affected by phase ($F(4, 2345) = 24.95$, $p < 0.001$) and group ($F(2, 2345) = 189.7$, $p < 0.001$). Agonistic approaches peaked during integration and stabilisation and declined thereafter (Fig. 1C). Group B showed the highest overall rates, while group A-N remained consistently low.

Proximity to the hay resource significantly affected agonistic approach frequency in both group B ($p < 0.001$) and group A ($p < 0.005$), but in opposite directions. In group B, more agonistic approaches occurred distant from the hay (median: 1.78, 95% CI: 1.339 – 2.5 approaches/h) compared to close to it (median: 0.28, 95% CI: 0.14 – 0.74 approaches/h). Conversely, in group A more agonistic approaches occurred close to the hay (median: 0.229, 95% CI: 0.2214 – 0.45 approaches/h) than distant from it (median: 0.1, 95% CI: 0.09 – 0.16 approaches/h, Suppl. Table 2 and 3).

Around the hay, both grouping phase ($F(4, 2223) = 18.03$, $p < 0.001$) and group ($F(2, 2223) = 21.32$, $p < 0.001$) significantly affected approach frequency, with rates peaking during integration - again driven by group B (Fig 4E). Distant from the hay, only group remained significant ($F(2, 2365) = 678.0$, $p < 0.001$), while phase was not ($F(4, 2365) = 2.10$, $p = 0.079$, Fig. 4F). Group B maintained higher levels of agonistic behaviour throughout, whereas other groups remained near zero.

Together, these results indicate that agonistic interactions were shaped not only by group and grouping phase but also by affiliation and proximity to the hay resource, with the strongest effects observed early in group formation and between closest associates.

Affiliative Approaches

At the individual level, the frequency of affiliative approaches differed significantly by group ($F(1, 17) = 38.97$, $p < 0.001$) but not grouping phase ($F(4,51) = 2.12$, $p = 0.092$, Fig 2D). Affiliation category significantly

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influenced the number of affiliative approaches ($p < 0.001$), with closest associates (median: 2.03, 95% CI: 1.79 - 2.41 approaches/h) showing markedly higher rates than both least frequent associates (median: 0.5, 95% CI: 0.37 – 0.64 approaches/h) and the group average (median: 0.82, 95% CI: 0.78 – 1 approaches/h, both $p < 0.001$, Fig. 3D, Table 2). Least frequent associates displayed the lowest frequencies overall, also compared to the overall group ($p < 0.05$).

At the group level, significant effects of grouping phase ($F(4, 2345) = 15.44$, $p < 0.001$) and group ($F(2, 2345) = 156.5$, $p < 0.001$) were observed (Fig. 1D). Group B (median: 2.13, 95% CI: 1.9 – 2.47) showed the highest overall frequencies of affiliative approaches throughout the study, followed by group A–Y (median: 1.46, 95% CI: 0.84 – 2.06) and group A–N (median: 0.58, 95% CI: 0.3 – 0.97, $p < 0.001$ for all pairwise comparisons), reflecting consistent group-level differences in affiliative tendencies.

Proximity to the hay resource significantly affected affiliative approach frequency for both groups ($p < 0.001$), with more affiliative approaches occurring distant from the hay than close to it (Suppl. Table 2 and 3). Affiliative approaches around the hay area also varied significantly with both grouping phase and group (phase: $F(4, 2223) = 2.43$, $p = 0.045$; group: $F(2, 2223) = 31.31$, $p < 0.001$, Fig. 4G). Group B exhibited higher rates than both A–Y and A–N during the introduction, integration, and consolidation phases (all $p < 0.001$), with minimal differences between the A–N and A–Y subgroups (Suppl. Table 2 and 3).

In contrast, affiliative approaches distant from the hay area varied significantly by group ($F(2, 2365) = 450.5$) but not by grouping phase ($F(44, 2365) = 1.53$, $p=0.19$). Affiliative approaches remained significantly higher in Group B than in A–N and A–Y ($p < 0.001$, Fig 4H).

Allogrooming

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At the individual level, allogrooming differed neither by group ($F(1,17) = 0.002$, $p = 0.963$) nor grouping phase ($F(4, 51) = 1.83$, $p = 0.138$, Fig. 2E, Table 1). Affiliation category significantly influenced allogrooming rates ($p < 0.001$) with closest associates (median: 1.7, 95% CI: 1.67 – 2.5) allogrooming significantly more than the overall group (median: 0.5, 95% CI: 0.45 – 0.64, $p < 0.001$) and least frequent associates (median: 0.04, 95% CI: 0.07 – 0.17, $p < 0.001$, Fig. 3E, Table 2). Least frequent associates displayed the lowest frequencies overall, also compared to the overall group ($p < 0.001$).

At the group level, allogrooming frequency differed significantly by group ($F(2, 2345) = 65$, $p < 0.001$) and grouping phase ($F(4, 2345) = 6.07$, $p < 0.001$) with allogrooming peaking in the integration phase for group B, in the introduction phase for group A-Y and in the follow-up phase in group A-N (table 1).

Activity budgets

The proportion of time allocated to eating increased significantly over the course of the study ($p=0.011$). Median eating time rose from 33.6% (95% CI = 28.7 - 37.4%) during the introduction phase to 40.4% (95% CI = 33 – 44.7%) at follow-up (Fig. 6).

The proportion of time spent resting did not change significantly over time ($p = 0.154$), though it rose non-significantly from the introduction (median: 37.3%, 95% CI = 35% - 40%) to follow-up (median: 40.8%, 95% CI = 36.4% - 46.3%, Fig. 6).

Conversely, the proportion of time spent active declined progressively and significantly across phases ($p < 0.001$). Median activity time decreased from 14.9% (95% CI = 13.3 -16.8%) during introduction to 8.3% (95% CI = 6.7 - 9.3%) at follow-up (Fig. 6).

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Overall, these results indicate a progressive behavioural stabilisation over the course of group development, with increasing allocation to feeding and resting, and decreasing active behaviour, suggesting reduced arousal and enhanced social and environmental habituation.

Discussion

The findings from both study groups indicate that equine social integration is a gradual, multi-month process characterized by progressive stabilization of spatial cohesion, affiliative interactions, and agonistic behaviour. High-resolution tracking provides quantitative evidence for this extended trajectory, revealing progressive increases in spatial cohesion (from 1.2% to 27.3% of time spent in close proximity (≤ 3m) within the first two months), accompanied by declining agonistic interactions, and dynamic reorganization of social network structures, consistent with the ongoing negotiation and consolidation of social relationships over several months following regrouping. Initial phases showed heightened agonism, reduced proximity, and rapidly shifting network structures, consistent with animals renegotiating spacing relationships and interaction patterns during early instability.[1,3,4,14,24,51,52,70,73–80]

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Interindividual distances decreased and correspondingly time spent in close proximity rose progressively, increasing from 1.2% to 27.3% within two months, indicating strengthening affiliative bonds and cohesive spatial organisation.[4,7,14,15,17,31,43,46,51,68,73,74,79,81–85] UWB-based tracking provided continuous, high-resolution quantification of these transitions, revealing fine-scale spatial restructuring that would be difficult to detect through intermittent behavioural sampling alone.[46,60] This increasing spatial cohesion coincided with significant declines in agonism and increases in affiliative contact, demonstrating progressive social integration in both groups.

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Familiarity strongly modulated this process and influenced early interaction patterns. Dyads with prior familiarity re-established affiliative contact quickly and formed closer proximity networks early, whereas unfamiliar horses (subgroup A-N) maintained greater distances until later. This pattern reflects well-established findings that familiarity reduces social tension and buffers the disruptive effects of regrouping by reducing the need for repeated agonistic assessment and facilitating faster integration and association.[1,22,32,40,51,52,65–67,74,86–88] The neurobiological basis for this effect likely involves the intrinsically rewarding and stress-buffering nature of affiliative contact, especially allogrooming, which reduces arousal and lowers heart rate.[3,9,18–23,85,89]. Consistent with these principles, our grouping process introduced new horses alongside a familiar companion rather than individually, a strategy designed to support smoother integration. Importantly, unfamiliar dyads also formed stable partnerships over time, indicating that prior relationships influenced the pace but not the eventual structure of the group.

Agonistic behaviour peaked early and declined steadily, a trajectory typical of groups transitioning from instability to social equilibrium.[1,3,8–10,14,48,51,52,64,74,78,89–94] Most agonistic interactions were ritualised and non-contact, and no clinically relevant injuries occurred, consistent with evidence that horses regulate access to space and resources primarily through ritualised displays rather than escalated aggression when spacing and resource access are adequate.[6,14,24,95] These findings suggest that even adult stallions may be introduced into social housing and maintained in stable groups when afforded sufficient space, familiarity, and minimal disruption, though the small group size and specific management context of Group B preclude broad generalisation without further replication.[14,79] Unexpectedly, agonistic interactions occurred at higher rates between closest associates, which may reflect either frequent low-intensity

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negotiation involved in maintaining preferred relationships or greater behavioural opportunity due to increased time spent in close proximity.

Activity budgets shifted markedly as the groups stabilised with horses spending more time resting or eating and less time in active locomotion during the stabilization and follow-up phases compared to the introduction period. Increased foraging and resting are associated with reduced arousal and improved welfare, while persistent vigilance and elevated locomotor activity are typical indicators of social tension.[85,96–101] Thus, the convergence of spatial metrics and time budgets supports the interpretation that regrouping causes temporary disruption, followed by a gradual return to relaxed behavioural states under favourable management conditions.

Resource distribution further shaped social dynamics. Although agonistic interactions were generally more frequent near feeding sites, the direction of this effect differed between groups. In Group B (n=4 horses, 1ha space, 24 feeding places), agonism was more common away from the hay, whereas in Group A (n = 15 horses, 830m^2 space, 24 feeding places) agonism occurred more frequently near the feeder. These patterns indicate that feeding areas do not universally serve as conflict hotspots or neutral areas, but rather that resource density, spacing opportunities and group composition determine how competition manifests in each social context.[24,46,48,64,85,102]

Affiliative interactions were consistently more common away from the hay in both groups, suggesting that non-feeding areas offer greater behavioural flexibility for positive social engagement. Early “brokers” in group A temporarily occupied central network positions around the hay. The individuals with elevated betweenness centrality functioned as connectors within the proximity network, while away from the feeder, degree centrality was largely uniform and betweenness near zero, indicating limited intermediary roles. Accordingly, these roles faded as the group stabilised, consistent with transient negotiations of spatial relationships around key

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resources.[14] Group B displayed a more egalitarian pattern from the outset. Multiple, dispersed feeding sites likely reduced bottlenecks and supported low-aggression regulation of access, a management approach shown to reduce aggression and improve welfare.[24,47,52,64,85,100,103,104]

Group differences in social integration must be interpreted in light of differing group compositions and resource availability. Whether the faster consolidation observed in Group B reflects group size, sex homogeneity, space availability, or their interaction requires further study. Because small, all-male groups represent a restricted social configuration relative to typical domestic herds,[1,8,14,79,92,102,105] caution is needed when extrapolating these patterns to larger mixed-sex populations. Differences between Groups A and B also involved multiple simultaneous factors (size, sex composition, space, housing type), precluding clear attribution of group-level patterns to any single variable. Controlled studies that manipulate space, resource density and group size independently are therefore necessary.

Individual removals for veterinary reasons in group A induced short-lived instability, as membership changes alter spacing and relationship negotiation even when no new individuals are added.[15,51,74,106] By the final observation period, group A stabilised at seven individuals, approximating typical free-ranging harem band sizes,[6,75,107,108] which may have facilitated renewed spatial cohesion, as smaller groups tend to maintain tighter spacing.[74] In addition to group-level constraints, methodological limitations should also be considered. Data loss is an inherent limitation of UWB tracking systems and is primarily associated with signal interference (e.g., enclosure structures). The higher proportion of excluded data in Group B likely reflects the larger spatial extent of the enclosure, increasing the likelihood of measurements exceeding the effective tracking range. Excluded data were distributed approximately evenly across grouping phases and spatial contexts (e.g., near vs. away from the hay feeder), suggesting no systematic bias in data removal. While this supports the robustness of the spatial

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dataset, it does not fully address limitations related to behavioural resolution. Although automated behavioural detection was validated, sensor-based quantification may still overlook subtle social interactions and context-dependent behaviours detectable through detailed ethological observation. Further studies are needed to determine whether minimizing social disruption and introducing horses alongside familiar companions consistently enhances welfare and social stability. This should include investigation of (1) larger and more diverse groups with varied ages and compositions, (2) the independent effects of space and group size, and (3) predictors of individual variation in integration pace, such as temperament and social history.

Returning to the original hypotheses, the results support a consistent trajectory of social integration while revealing important context dependent mechanisms. Hypothesis 1, predicting a progressive decrease in inter individual distances, was strongly supported across both groups, with clear and continuous convergence toward closer spatial cohesion over time. This finding supports the central premise that social integration in horses follows a gradual and measurable process of increasing proximity and stabilising affiliative relationships. Horses introduced alongside familiar companions showed faster and more stable early affiliative patterns than those introduced without familiar partners, supporting Hypothesis 3 and indicating that prior familiarity accelerates this process without altering its overall trajectory. Hypothesis 2, proposing a positive association between feeder proximity and agonistic behaviour, was only partially supported and depended on context. Agonism was elevated near the hay feeder in Group A, consistent with competitive exclusion at a concentrated resource, whereas the opposite pattern in Group B indicates that resource related conflict emerges from the interaction between resource density, available space, and group composition rather than from feeder proximity alone.

Taken together, these findings indicate that while the trajectory of social stabilisation is highly consistent, the mechanisms shaping interaction

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patterns, particularly the role of resources as conflict foci, are strongly influenced by contextual and management factors. Across both groups, increasing cohesion, declining agonism, and stabilising network and activity patterns show that social stabilisation is a gradual process that often requires several months for domestic horses to reach full stability after regrouping. Although measurable improvements in cohesion and reductions in agonism emerged within weeks, full stabilisation of partner preferences, proximity networks, and spatial organisation extended over several months, consistent with previous reports.[14,51,74,106] This has direct implications for management, as as changes in group composition during this period are likely to disrupt still forming social structures and prolong instability. Management should therefore prioritise minimising unnecessary social disruption, introducing horses alongside familiar companions, providing sufficient space and multiple distributed feeding sites, and allowing adequate time for social reorganisation. Further work across a broader range of group sizes, compositions, and management conditions is required to refine context specific recommendations.

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Conflict of Interest: The authors have no competing interests to declare that are relevant to the content of this article.

Ethics Approval: This study was non-invasive and entailed only monitoring the horses under their current conditions of life. No specific veterinary treatments or interventions were carried out for the purpose of this study. The Institutional Ethics Committee of the University of Veterinary Medicine Vienna waived ethical approval for the study (ETK-152/09/2019) in accordance with the “Good Scientific Practice. Ethics in Science and Research” guidelines implemented at the University of Veterinary Medicine Vienna and national legislation. The animal experiment for group B was additionally approved by the Swiss Cantonal authorities under license number 36917. All methods were carried out in accordance with relevant

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guidelines and regulations. The experiments are reported in accordance with the ARRIVE guidelines.

Funding: This study was funded by the Sandgrueb-Stiftung and Gut Aiderbichl.

Data availability: The datasets generated and analysed during the current study are included in this published article (and its Supplementary Information files) are available from the corresponding author upon reasonable request.

Author contributions

Conceptualization: F.J.; study design: U.A. and F.J.; Data collection: L.T.B., Z.K., M.C., U.A., and F.J., Data analysis: L.T.B. and F.J.; writing: L.T.B. and F.J.; All authors have read and approved the manuscript.

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Acknowledgements

We gratefully acknowledge Dr. Sabrina Briefer Freymond for her support of the research activities at Agroscope, Swiss National Stud and for her valuable contributions to the preparation of this manuscript.

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Figure Legends:

Figure 1: Time Course of Spatiotemporal and Behavioural Parameters During Grouping (group level)

(A) Interindividual distances in group B, subgroup A-Y (introduced together) and subgroup A-N (introduced separately) throughout the different grouping phases

(B) Time spent in proximity (≤ 3m) throughout the different grouping phases

(C) Agonistic approaches per hour throughout the different grouping phases

(D) Affiliative approaches per hour throughout the different grouping phases

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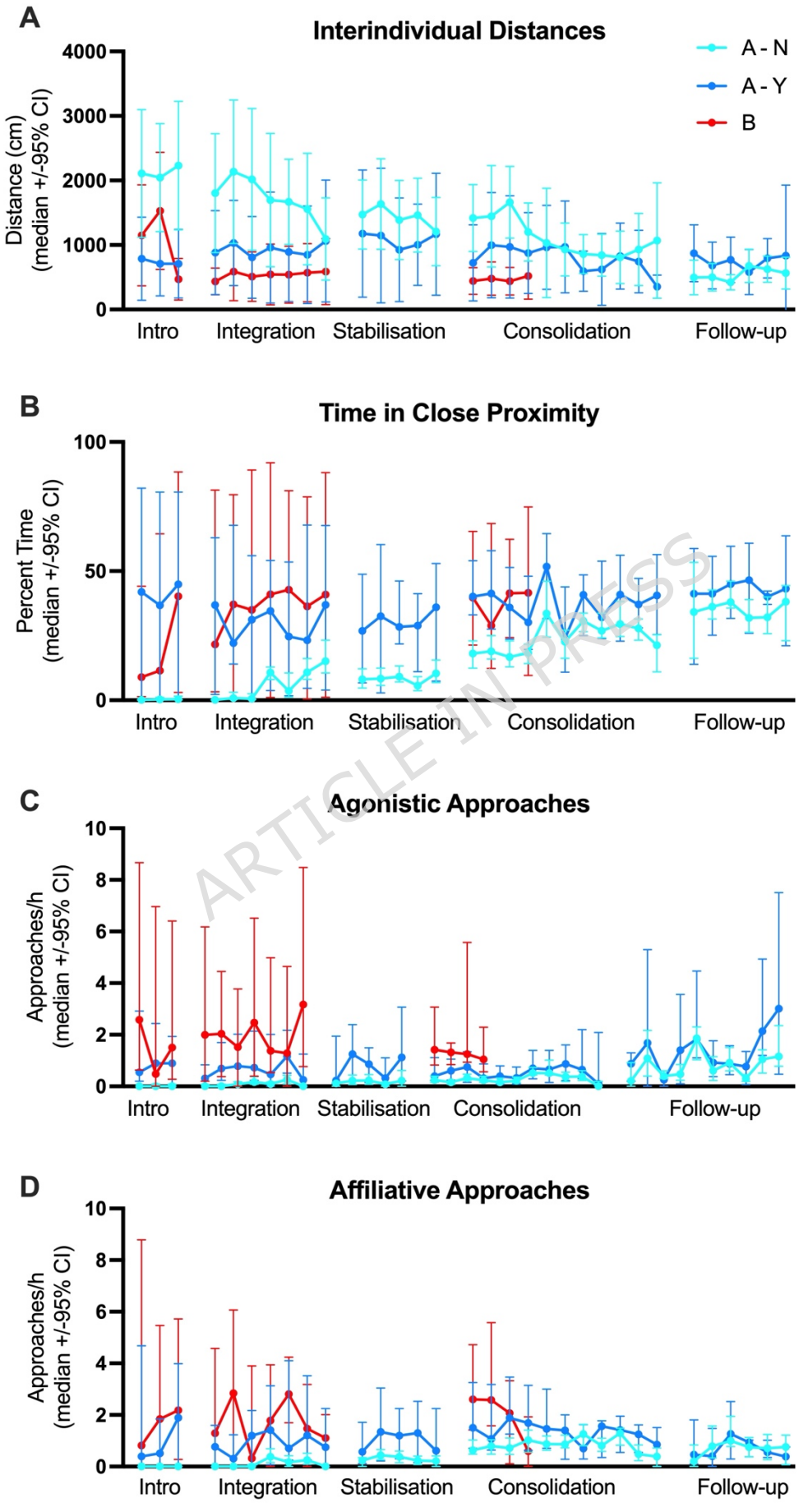

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Figure 2: Scatter Plots of the different spatiotemporal and behavioural parameters measured and calculated in this study at the individual level.
The scatter plots illustrate the substantial differences between dyads. The medians (± 95% CI) are indicated by red lines. Statistical significance is indicated as* p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001
(A)Dyadic inter-individual distance (cm)
(B) Percentage of time spent in close proximity (< 3 m)
(C) Rate of agonistic approaches per hour
(D) Rate of affiliative approaches per hour
(E) Rate of allogrooming per hour
(F) Rate of high intensity retreats per hour

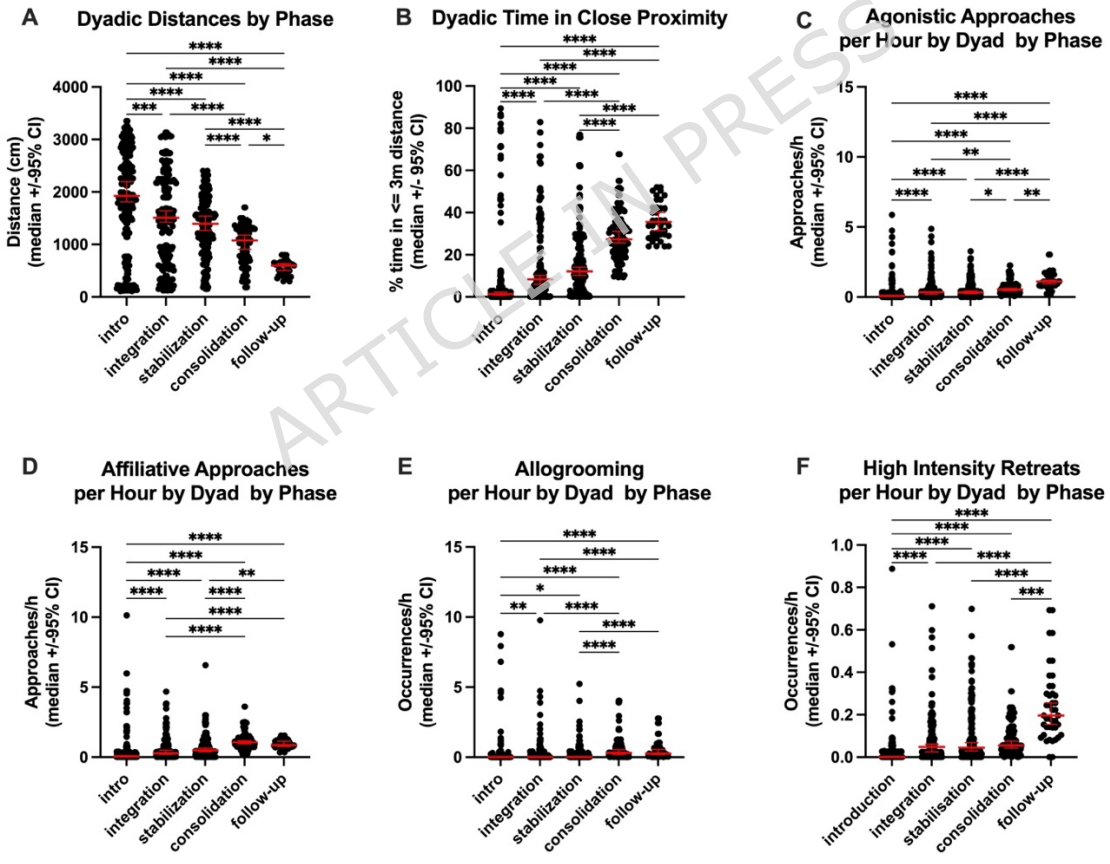

Figure 3: Spatiotemporal and Behavioural Parameters by Affiliation (individual level)

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The least frequent associates (for each horse the group member it spent least time at a distance ≤ 3m with) are indicated by a “q“/”L”, the closest associates (for each horse the group member it spent most time at a distance ≤ 3m with), are indicated by a “x”/”C” and the group average by a dot/”A”. Statistical significance is indicated as * $p<0.05$, ** $p<0.01$, *** $p<0.001$, **** $p<0.0001$

(A) Percentage of time (median ± 95% CI) spent in close proximity per dyad by grouping phase and affiliation in group A (blue) and B (red).

(B) Time (%) spent in close proximity per dyad by affiliation.

(C) Interindividual Distances (cm) per dyad by affiliation

(D) Affiliative approaches per hour by affiliation

(E) Allogrooming events per hour by affiliation

(F) Agonistic approaches per hour by affiliation

(G) High intensity retreats per hour by affiliation

(H) Low intensity retreats per hour by affiliation

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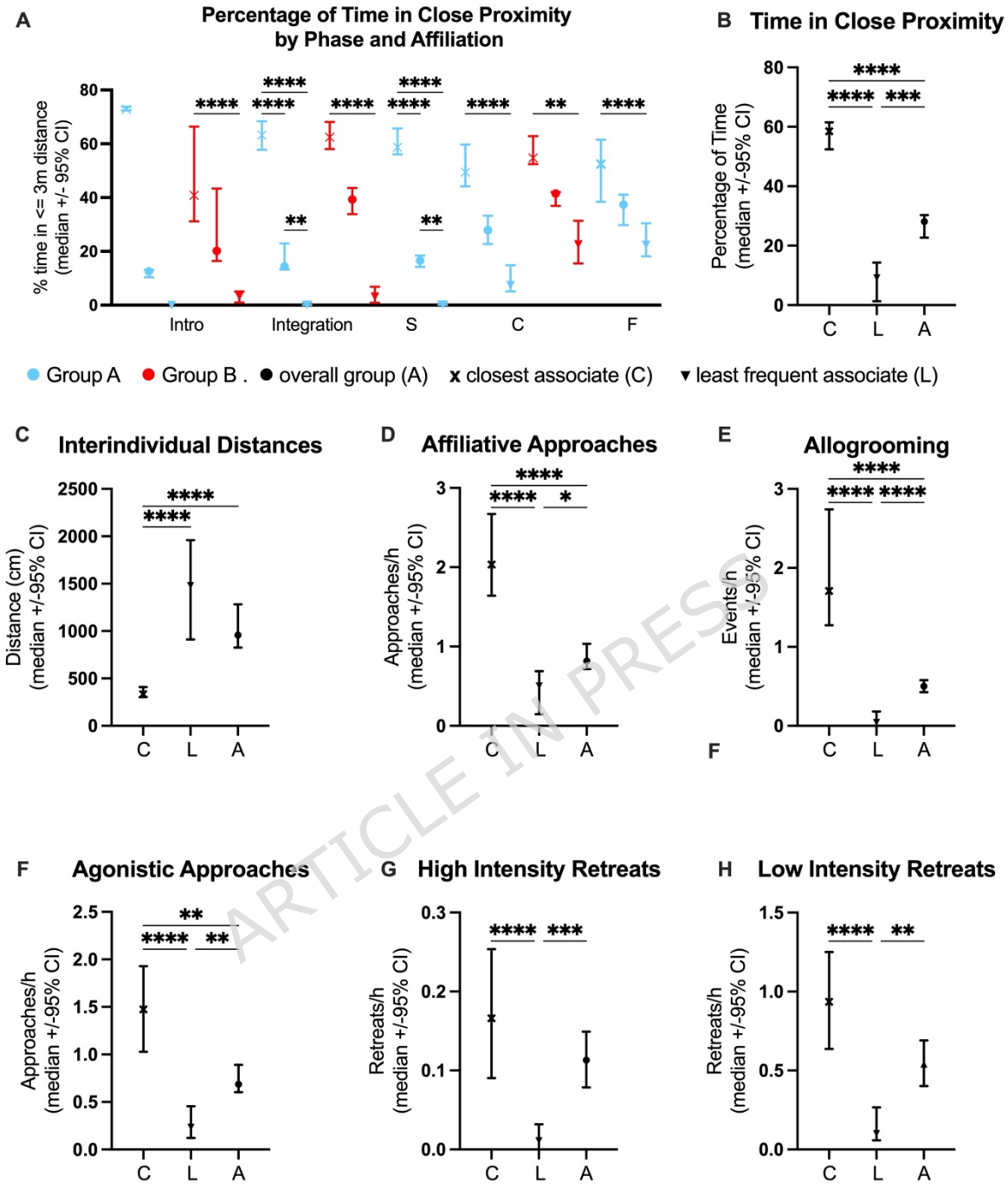

Figure 4: Inter-individual distances, social proximity, agonistic and affiliative approaches by group across grouping phases in the proximity to the hay resource versus distant to it (group level).

Blue (group A-Y) and red (group B) represent horses introduced together, cyan represents horses introduced separately (A–N). Statistical significance

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is indicated as * p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001

A) and B): Inter-individual distances (median ± 95% CI) near the hay (A) and away from the hay feeder per phase

C) and D) Percentage of time (median ± 95% CI) spent in close proximity (< 3 m) around the hay feeder (C) and distant from the hay (D) per phase.

E) and F) Agonistic approaches per hour (median ± 95% CI) near the hay (E) and away from the hay feeder (F) per phase

G) and H) Affiliative approaches per hour (median ± 95% CI) near the hay (G) and away from the hay feeder (H) per phase

I) Comparison of interindividual distances overall between around the hay feeder and distant from the hay

J) Comparison of agonistic approaches overall between around the hay feeder and distant from the hay

K) Comparison of agonistic approaches/interindividual distances overall between around the hay feeder and distant from the hay

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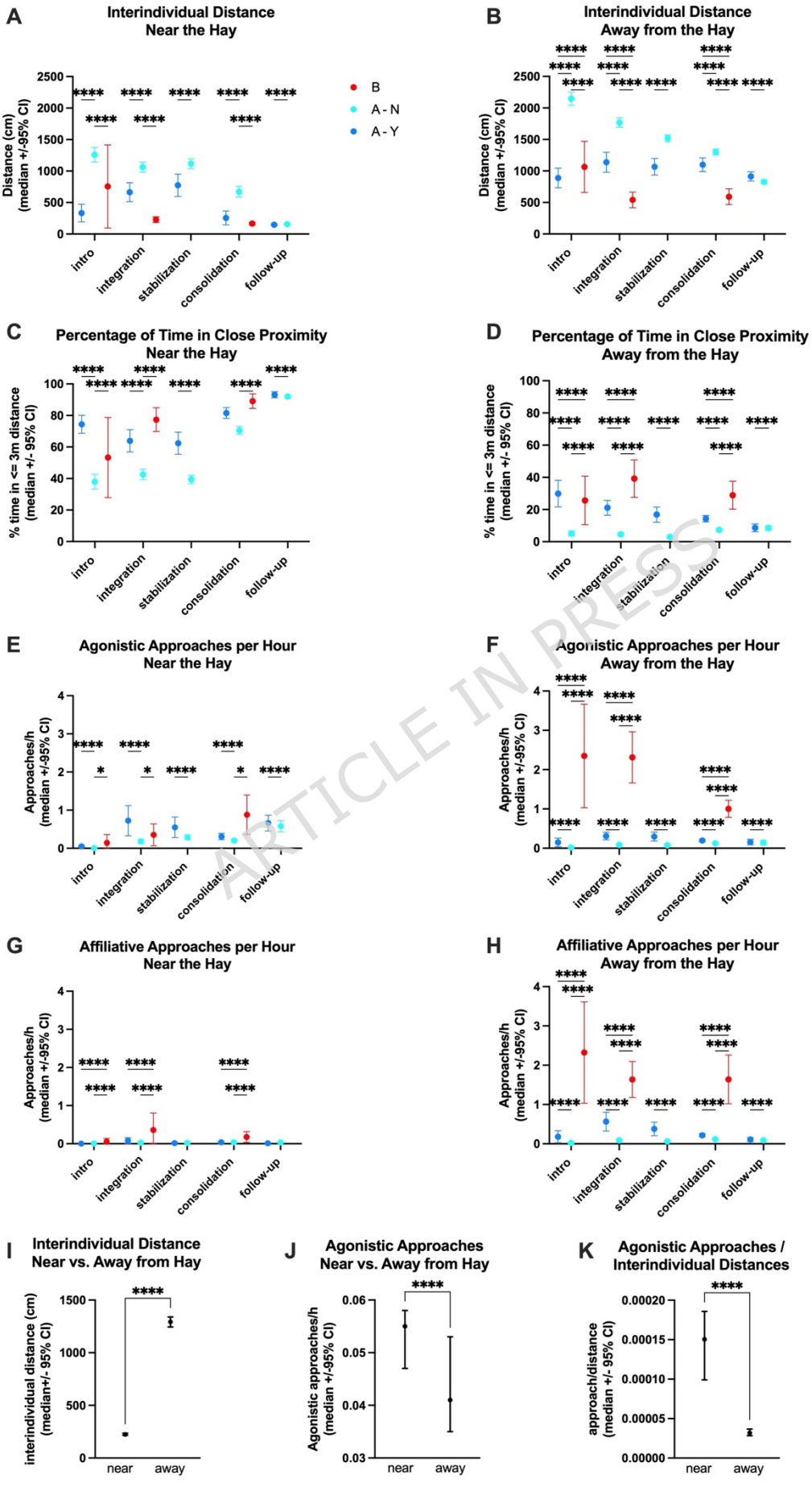

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Figure 5. Proximity-based association networks.
Networks were constructed for Group A and Group B across experimental periods (introduction, integration, stabilization, consolidation, and follow-up) and conditions (near and away from hay feeders). Nodes represent individuals, and edges represent dyadic association strength, defined as the proportion of time dyads spent within 300 cm. Networks are undirected and weighted, with higher edge weights indicating stronger spatial association.

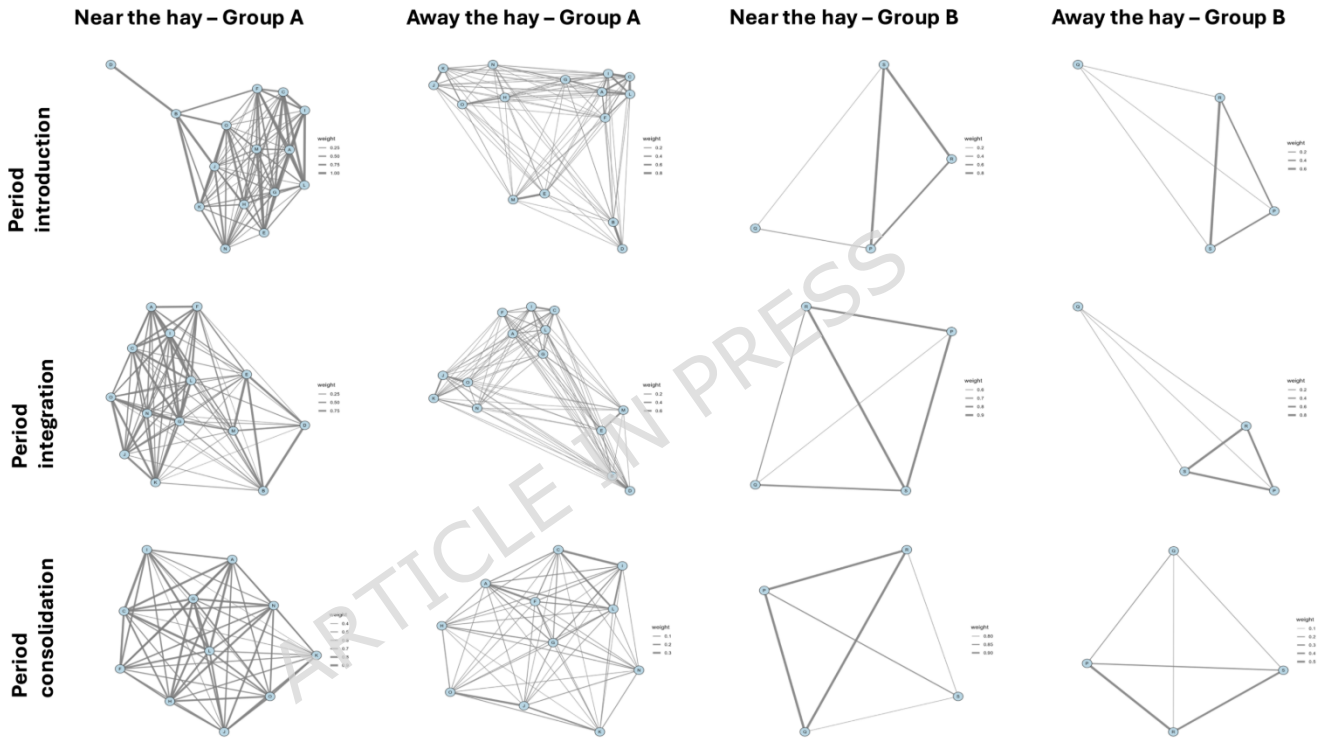

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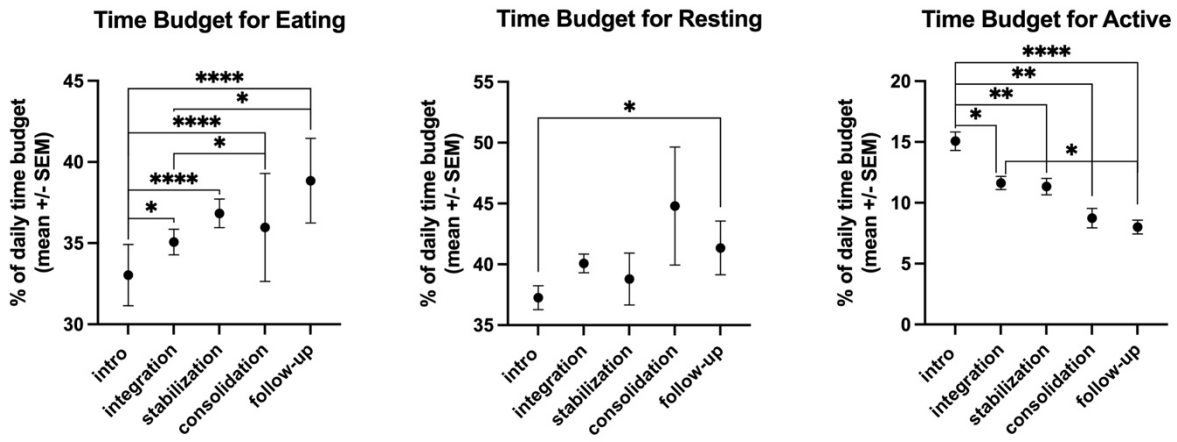
Figure 6: Activity budgets across grouping phases.
The time budgets are indicated as percentage of daily activity per grouping phase. As the data were normally distributed (D'Agostino & Pearson test), data are represented as mean +/- SEM. * $p<0.05$, ** $p<0.01$, *** $p<0.001$, **** $p<0.0001$
A) Time budget for eating
B) Time budget for resting
C) Time budget for activity/locomotion



Tables

Table 1: Descriptive statistics of the different spatiotemporal and behavioural parameters measured and calculated in this study by group (A vs. B)/subgroup (introduced together: A-Y, not introduced together: A-N) and grouping phase (introduction, integration, stabilization, consolidation and follow-up).

			A overall	A - Y	A - N	B
Distance	Intro	Median (95%CI)	1892.0 (1815.5 – 1935.8)	448.5 (241.8 – 1562.3)	1960.5 (1906.2 – 2116.5)	772.5 (452.0 – 1556.6)
	Integ.	Median (95%CI)	1590.8 (1463.5 – 1700.8)	635.8 (388.2 – 1225.0)	1695.5 (1561.4 – 1766.0)	510.3 (180.0 – 888.8)
	Stab.	Median (95%CI)	1389.2 (1283.8 – 1499.9)	734.1 (492.5 – 984.0)	1451.2 (1358.5 – 1558.2)	
	Cons.	Median (95%CI)	936.2 (877.2 – 993.2)	589.5 (472.9 – 710.5)	1000.8 (945.5 – 1067.0)	394.4 (300.0 – 573.7)
	Foll.	Median (95%CI)	531.2 (499.0 – 574.5)	490.0 (334.8 – 681.0)	537.0 (506.0 – 581.0)	
% Time	Intr o	Median (95%CI)	0.3 (0.2 – 0.7)	38.5 (0.9 – 59.2)	0.2 (0.1 – 0.4)	9.8 (4.3 – 32.5)
	Inte g	Median (95%CI)	6.3 (3.6 – 9.4)	31.3 (19.6 – 37.9)	3.3 (1.9 – 6.7)	22.5 (4.5 – 72.7)
	Sta b	Median (95%CI)	9.8 (8.2 – 11.8)	29.5 (25.3 – 39.4)	8.1 (7.3 – 9.7)	
	Con s	Median (95%CI)	26.3 (25.0 – 27.4)	38.3 (34.7 – 41.0)	24.3 (22.5 – 25.6)	40.0 (26.5 – 50.1)

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	Foll.	Median (95%CI)	34.6 (32.2 – 36.2)	38.0 (35.4 – 47.8)	33.5 (31.4 – 35.6)	
Affiliative Approaches	Intr a	Median (95%CI)	0.0 (0.0 – 0.0)	0.4 (0.0 – 1.8)	0.0 (0.0 – 0.0)	1.1 (0.3 – 4.1)
	Inte a	Median (95%CI)	0.1 (0.0 – 0.1)	1.0 (0.5 – 1.2)	0.0 (0.0 – 0.1)	1.5 (0.9 – 2.5)
	Sta b	Median (95%CI)	0.3 (0.2 – 0.4)	0.9 (0.6 – 1.3)	0.3 (0.2 – 0.4)	
	Con c	Median (95%CI)	0.9 (0.8 – 0.9)	1.4 (1.2 – 1.5)	0.8 (0.7 – 0.9)	2.2 (1.4 – 2.6)
	Foll.	Median (95%CI)	0.8 (0.7 – 0.9)	0.6 (0.4 – 1.0)	0.8 (0.7 – 0.9)	
Allogrooming	Intr a	Median (95%CI)	0.0 (0.0 – 0.0)	0.2 (0.0 – 0.8)	0.0 (0.0 – 0.0)	0.0 (0.0 – 0.1)
	Inte a	Median (95%CI)	0.0 (0.0 – 0.0)	0.1 (0.0 – 0.4)	0.0 (0.0 – 0.0)	0.0 (0.0 – 0.0)
	Sta b	Median (95%CI)	0.0 (0.0 – 0.0)	0.2 (0.0 – 0.5)	0.0 (0.0 – 0.0)	
	Con c	Median (95%CI)	0.1 (0.1 – 0.2)	0.8 (0.4 – 1.0)	0.1 (0.0 – 0.1)	0.0 (0.0 – 0.2)
	Foll.	Median (95%CI)	0.1 (0.1 – 0.2)	0.1 (0.0 – 0.3)	0.2 (0.1 – 0.3)	
Agonistic Approaches	Intr a	Median (95%CI)	0.0 (0.0 – 0.1)	0.8 (0.2 – 1.7)	0.0 (0.0 – 0.0)	1.5 (0.5 – 2.6)
	Inte a	Median (95%CI)	0.1 (0.1 – 0.2)	0.6 (0.5 – 0.8)	0.1 (0.1 – 0.1)	1.8 (0.9 – 3.1)
	Sta b	Median (95%CI)	0.2 (0.1 – 0.2)	0.8 (0.4 – 1.1)	0.1 (0.1 – 0.2)	
	Con c	Median (95%CI)	0.3 (0.3 – 0.4)	0.6 (0.4 – 0.7)	0.3 (0.2 – 0.3)	1.2 (1.1 – 1.6)
	Foll.	Median (95%CI)	0.8 (0.6 – 1.0)	1.1 (0.8 – 1.3)	0.7 (0.6 – 0.9)	
High Intensity Retreats	Intr a	Median (95%CI)	0.0 (0.0 – 0.0)	0.0 (0.0 – 0.1)	0.0 (0.0 – 0.0)	0.0 (0.0 – 0.2)
	Inte a	Median (95%CI)	0.0 (0.0 – 0.0)	0.0 (0.0 – 0.1)	0.0 (0.0 – 0.0)	0.2 (0.0 – 0.3)
	Sta b	Median (95%CI)	0.0 (0.0 – 0.0)	0.1 (0.0 – 0.1)	0.0 (0.0 – 0.0)	
	Con c	Median (95%CI)	0.0 (0.0 – 0.0)	0.0 (0.0 – 0.1)	0.0 (0.0 – 0.0)	0.0 (0.0 – 0.1)
	Foll.	Median (95%CI)	0.1 (0.0 – 0.1)	0.1 (0.0 – 0.3)	0.1 (0.0 – 0.1)	
Low Intensity	Intr a	Median (95%CI)	0.0 (0.0 – 0.1)	0.3 (0.1 – 0.7)	0.0 (0.0 – 0.0)	0.5 (0.1 – 1.1)
	Inte a	Median (95%CI)	0.1 (0.1 – 0.1)	0.4 (0.2 – 0.5)	0.0 (0.0 – 0.1)	0.7 (0.4 – 1.5)
	Sta b	Median (95%CI)	0.1 (0.1 – 0.1)	0.4 (0.2 – 0.7)	0.1 (0.1 – 0.1)	

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	Foll.Con.	Median (95%CI)	0.2 (0.2 – 0.2)	0.3 (0.2 – 0.4)	0.1 (0.1 – 0.2)	0.6 (0.5 – 0.8)
	Foll.	Median (95%CI)	0.7 (0.5 – 0.8)	0.9 (0.5 – 1.3)	0.6 (0.4 – 0.7)	

Table 2: Descriptive statistics of the different dyadic spatiotemporal and behavioural parameters measured and calculated in this study by group (A, B) and affiliation level (closest associates (=conspecific a horse spent most time at ≤ 3m), least frequent associate, overall group) and grouping phase (introduction, integration, stabilization, consolidation, follow-up). For each horse one closest and one least frequent associate is considered.

			Group A			**Group B**		
			closest	**least**	**overall**	**closest**	**least**	**overall**
Distance	Intro	Median (95%CI)	121.00 (119.00 – 306.00)	3060.50 (2267.50 – 3404.50)	1892.0 (1815.5 – 1935.8)	338.50 (225.00 – 2257.50)	1871.75 (1241.50 – 2257.50)	772.5 (452.0 – 1556.6)
	Integ.	Median (95%CI)	221.00 (192.50 – 286.25)	2522.00 (2395.00 – 3000.00)	1590.8 (1463.5 – 1700.8)	126.00 (125.00 – 888.00)	996.25 (888.00 – 1013.00)	510.3 (180.0 – 888.8)
	Stab.	Median (95%CI)	333.00 (279.62 – 666.00)	1085.00 (928.62 – 1206.00)	1389.2 (1283.8 – 1499.9)			
	Cons.	Median (95%CI)	301.00 (268.00 – 486.00)	1989.75 (1514.75 – 2172.62)	936.2 (877.2 – 993.2)	166.75 (130.00 – 296.50)	2078.50 (1922.00 – 2103.00)	394.4 (300.0 – 573.7)
	Foll.	Median (95%CI)	279.25 (268.75 – 351.50)	696.12 (652.25 – 798.00)	531.2 (499.0 – 574.5)			
Affiliative Approaches	Intro	Median (95%CI)	2.86 (1.73 – 4.62)	0.00 (0.00 – 0.00)	0.4 (0.0 – 1.8)	4.91 (0.41 – 5.47)	0.27 (0.13 – 0.41)	1.1 (0.3 – 4.1)
	Integ.	Median (95%CI)	2.32 (1.75 – 3.67)	0.00 (0.00 – 0.00)	1.0 (0.5 – 1.2)	2.68 (1.44 – 3.16)	0.40 (0.00 – 1.44)	1.5 (0.9 – 2.5)
	Stab.	Median (95%CI)	1.40 (1.09 – 2.41)	0.68 (0.40 – 0.95)	0.9 (0.6 – 1.3)			

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	Cons.	Median (95%CI)	2.43 (1.60 – 2.65)	0.00 (0.00 – 0.07)	1.4 (1.2 – 1.5)	4.92 (2.40 – 7.21)	0.00 (0.00 – 0.00)	2.2 (1.4 – 2.6)
	Foll.	Median (95%CI)	0.63 (0.61 – 1.68)	0.73 (0.57 – 0.98)	0.6 (0.4 – 1.0)			
Allogrooming	Intro	Median (95%CI)	4.18 (1.09 – 6.69)	0.00 (0.00 – 0.00)	0.2 (0.0 – 0.8)	0.00 (0.00 – 0.27)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.1)
	Integ.	Median (95%CI)	1.45 (0.94 – 2.81)	0.00 (0.00 – 0.00)	0.1 (0.0 – 0.4)	1.69 (0.00 – 2.12)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.0)
	Stab.	Median (95%CI)	0.87 (0.34 – 1.18)	0.00 (0.00 – 0.00)	0.2 (0.0 – 0.5)			
	Cons.	Median (95%CI)	0.91 (0.37 – 1.43)	0.00 (0.00 – 0.00)	0.8 (0.4 – 1.0)	3.58 (1.43 – 4.12)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.2)
	Foll.	Median (95%CI)	0.34 (0.19 – 1.61)	0.00 (0.00 – 0.34)	0.1 (0.0 – 0.3)			
Agonistic Approaches	Intro	Median (95%CI)	2.43 (1.66 – 3.22)	0.00 (0.00 – 0.00)	0.8 (0.2 – 1.7)	4.24 (0.76 – 5.76)	0.41 (0.27 – 0.76)	1.5 (0.5 – 2.6)
	Integ.	Median (95%CI)	1.19 (0.83 – 2.45)	0.00 (0.00 – 0.00)	0.6 (0.5 – 0.8)	3.37 (0.89 – 4.45)	0.57 (0.38 – 0.89)	1.8 (0.9 – 3.1)
	Stab.	Median (95%CI)	0.64 (0.40 – 0.90)	0.20 (0.16 – 0.51)	0.8 (0.4 – 1.1)			
	Cons.	Median (95%CI)	1.24 (0.78 – 2.58)	0.04 (0.00 – 0.08)	0.6 (0.4 – 0.7)	2.40 (0.65 – 3.00)	0.00 (0.00 – 0.00)	1.2 (1.1 – 1.6)
	Foll.	Median (95%CI)	0.61 (0.57 – 1.11)	0.82 (0.29 – 1.06)	1.1 (0.8 – 1.3)			

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High Intensity Retreats	Intro	Median (95%CI)	0.08 (0.00 – 0.24)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.1)	0.26 (0.00 – 0.38)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.2)
	Integ.	Median (95%CI)	0.15 (0.08 – 0.22)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.1)	0.20 (0.12 – 0.59)	0.00 (0.00 – 0.12)	0.2 (0.0 – 0.3)
	Stab.	Median (95%CI)	0.00 (0.00 – 0.06)	0.00 (0.00 – 0.00)	0.1 (0.0 – 0.1)			
	Cons.	Median (95%CI)	0.15 (0.11 – 0.43)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.1)	0.07 (0.00 – 0.37)	0.00 (0.00 – 0.00)	0.0 (0.0 – 0.1)
	Foll.	Median (95%CI)	0.10 (0.00 – 0.15)	0.04 (0.00 – 0.15)	0.1 (0.0 – 0.3)			
Low Intensity Retreats	Intro	Median (95%CI)	0.64 (0.46 – 1.41)	0.00 (0.00 – 0.00)	0.3 (0.1 – 0.7)	1.55 (0.14 – 2.00)	0.14 (0.00 – 0.14)	0.5 (0.1 – 1.1)
	Integ.	Median (95%CI)	0.56 (0.31 – 0.92)	0.00 (0.00 – 0.00)	0.4 (0.2 – 0.5)	1.42 (0.30 – 2.18)	0.12 (0.10 – 0.30)	0.7 (0.4 – 1.5)
	Stab.	Median (95%CI)	0.24 (0.16 – 0.56)	0.16 (0.08 – 0.31)	0.4 (0.2 – 0.7)			
	Cons.	Median (95%CI)	0.55 (0.33 – 1.87)	0.00 (0.00 – 0.08)	0.3 (0.2 – 0.4)	0.80 (0.14 – 1.87)	0.00 (0.00 – 0.00)	0.6 (0.5 – 0.8)
	Foll.	Median (95%CI)	0.52 (0.50 – 0.82)	0.85 (0.37 – 0.88)	0.9 (0.5 – 1.3)			

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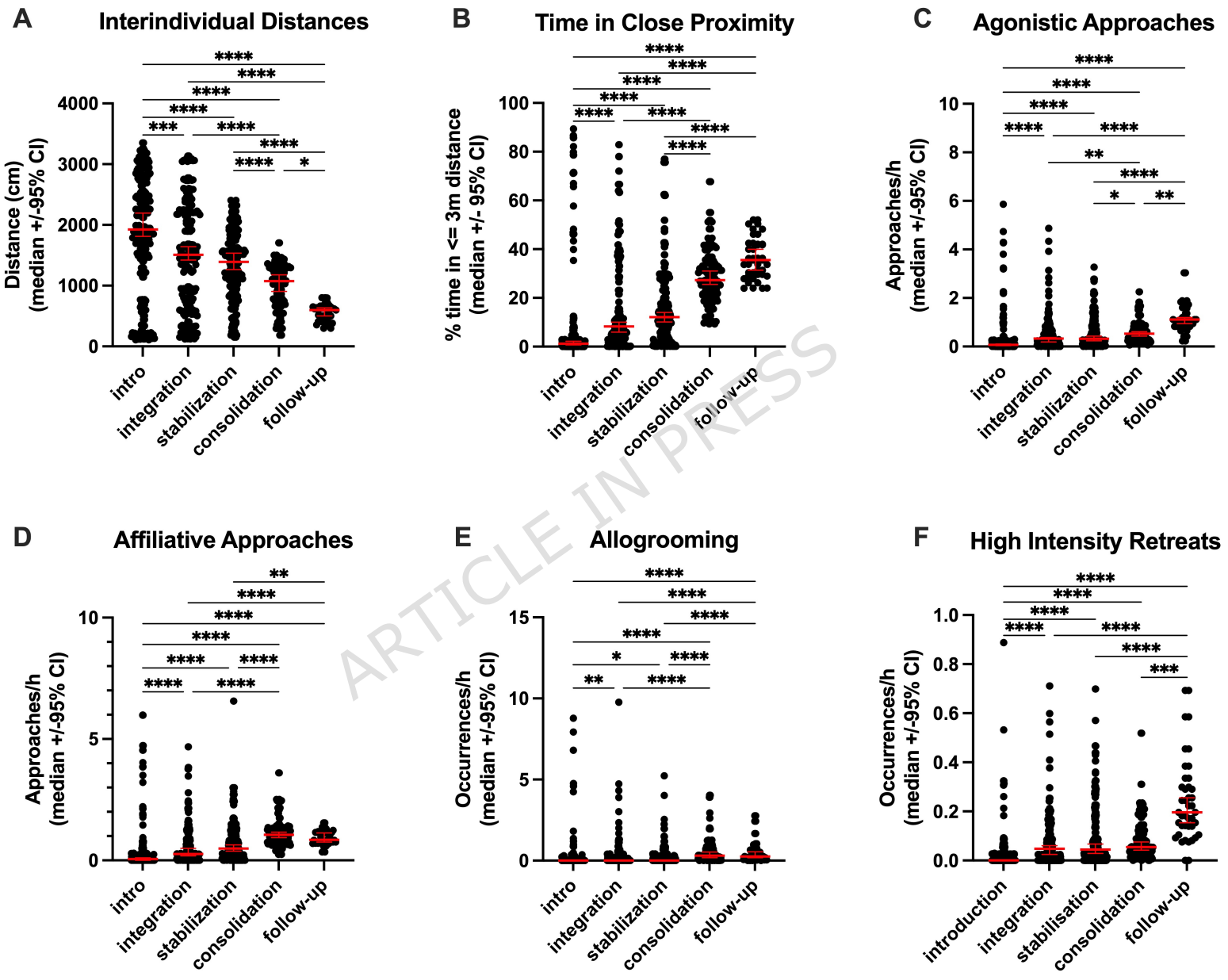

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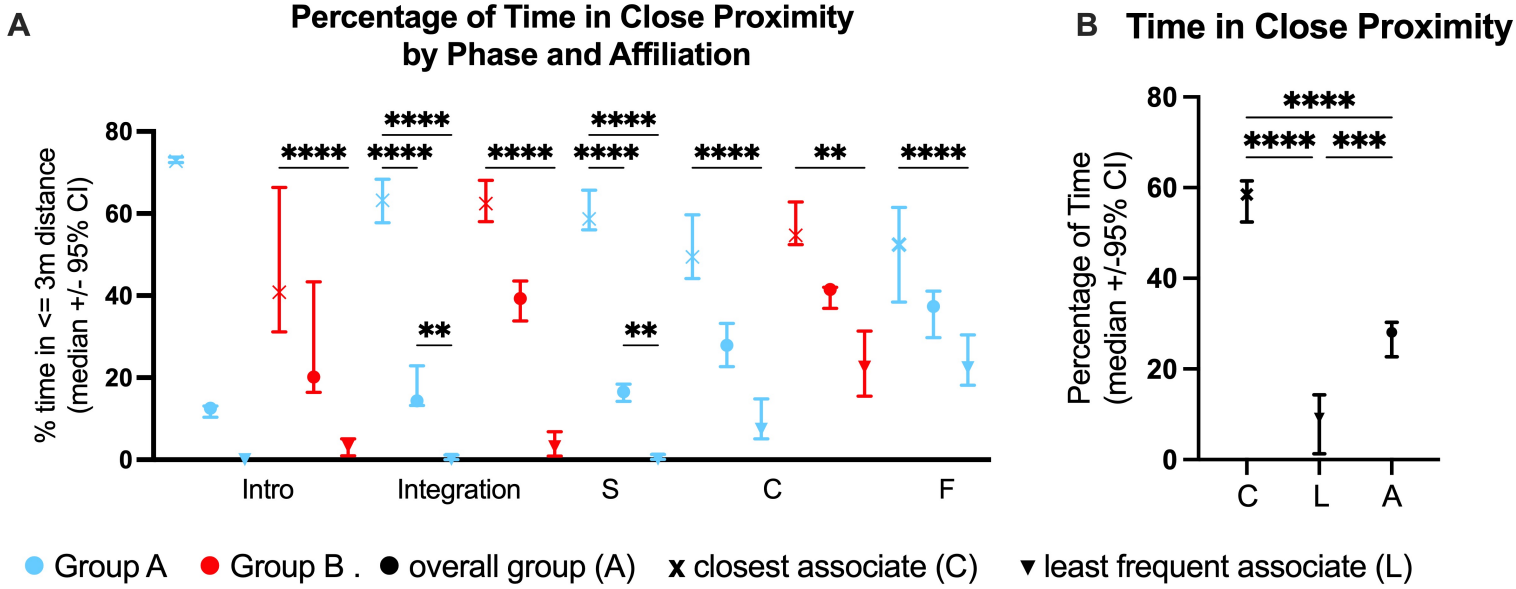

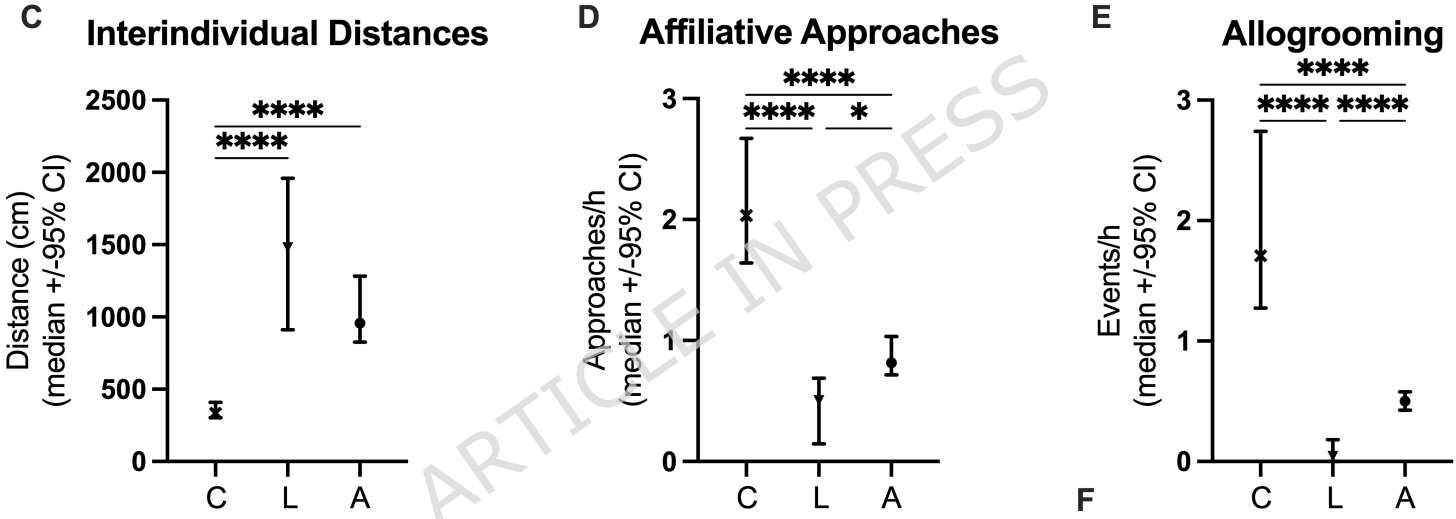

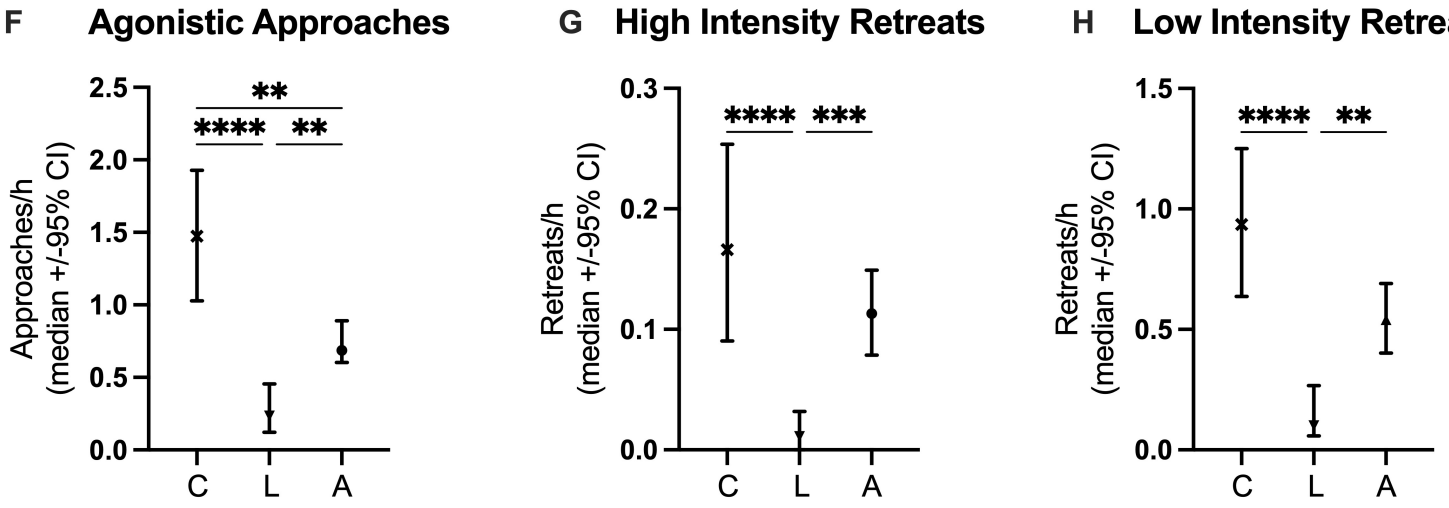

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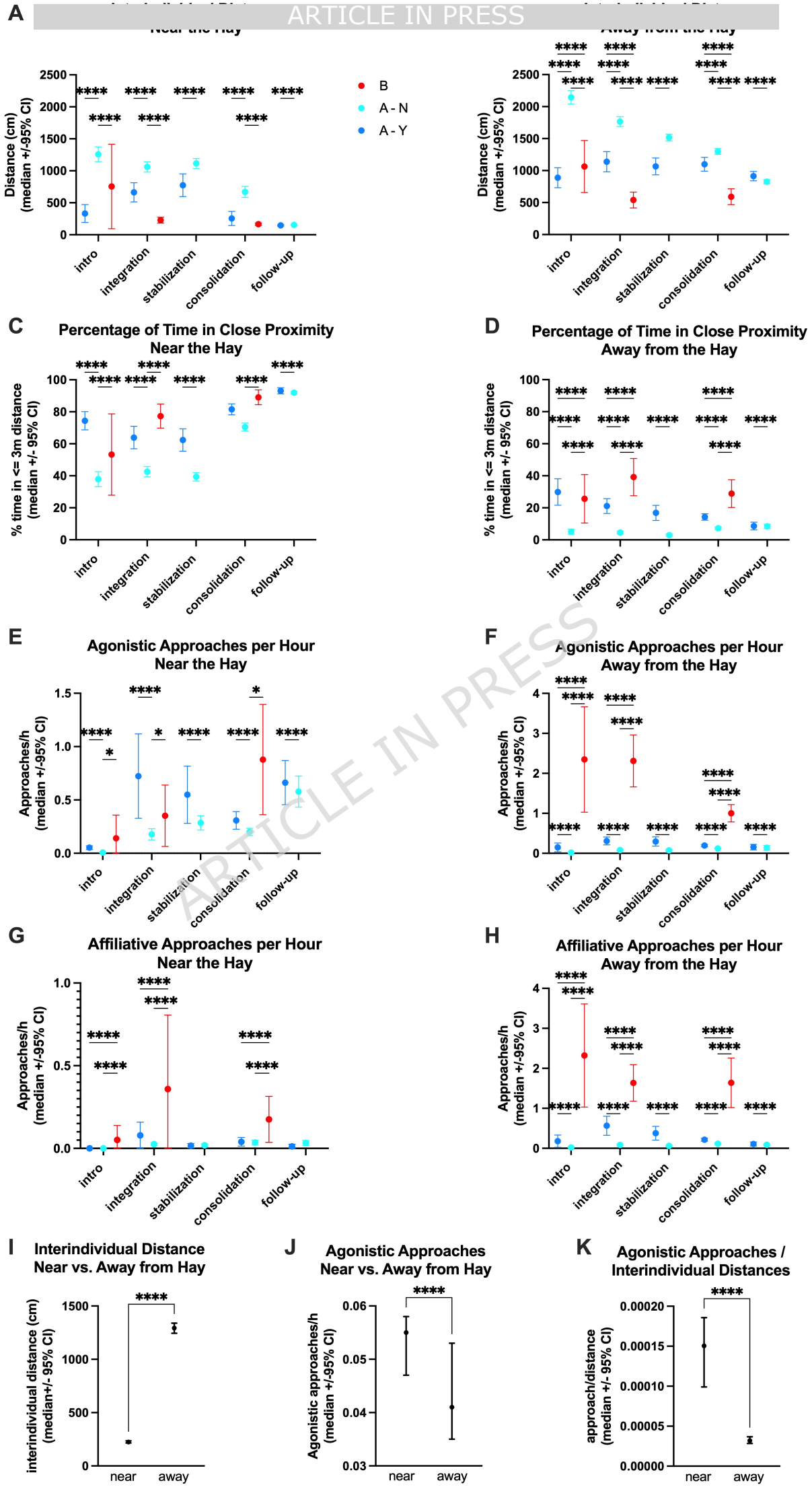

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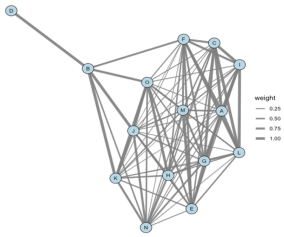
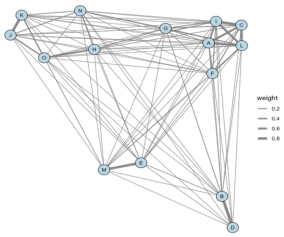
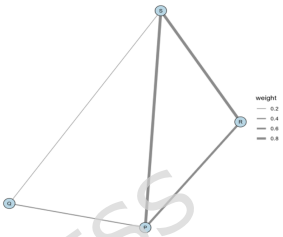
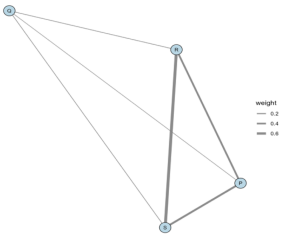
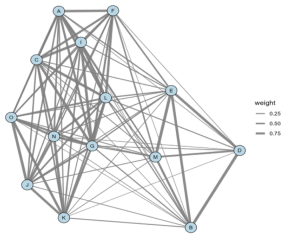
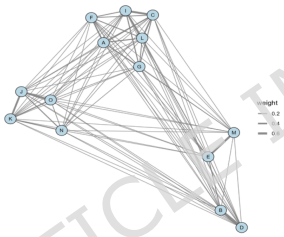
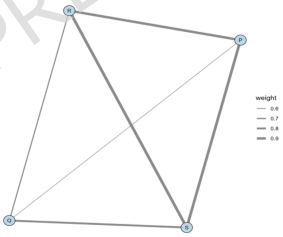
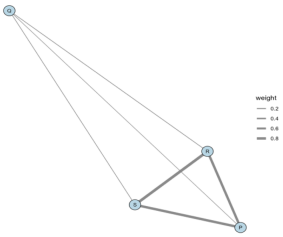
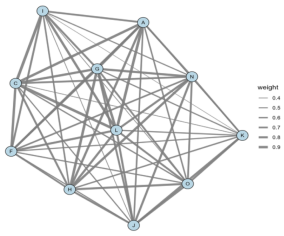
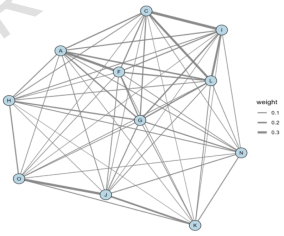
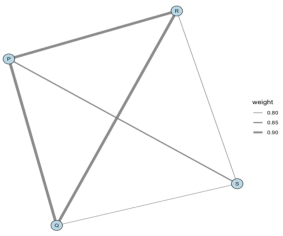
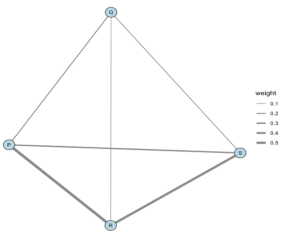
Period introduction				
Period integration				
Period consolidation				

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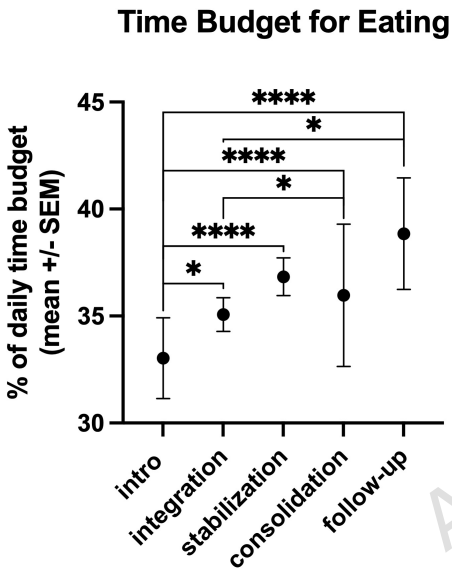

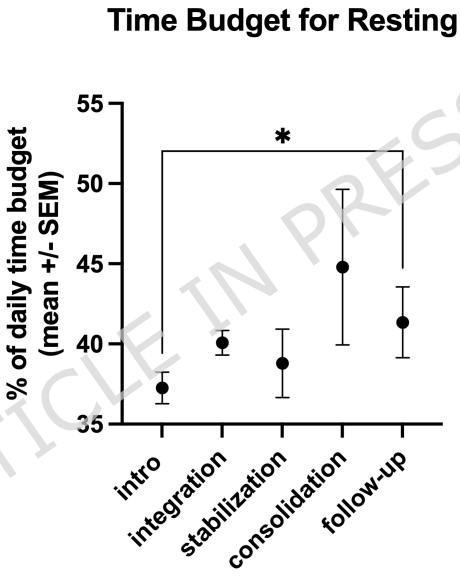

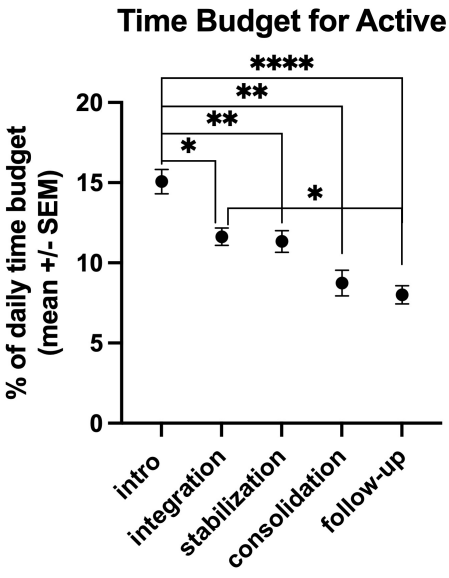

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