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ABSTRACT

Background: The darknet hosts an increasing number of hidden services dedicated to the distribution of child sexual abuse material (CSAM). Given that by contributing CSAM to the forum members subject themselves to criminal prosecution, questions regarding the motivation for members contributing to darknet CSAM forums arise.

Objective: Building on insights gained from research into clearnet communities, here we examine the extent to which social incentives generated by the online CSAM community may explain members' posting behavior on darknet CSAM forums.

Participants and setting: We analyze digital forensic artifacts on the online behavior of members of a darknet CSAM forum that was shut down by law enforcement agencies in July 2015.

Methods: We apply group-based trajectory modelling (GBTM), social network analysis, and mixed-effect survival models.

Results: Applying GBTM three posting trajectories can be distinguished. Social network analyses finds the reply network to be more centralized than predicted by chance. Mixed-effect survival models show positive associations between the length of members' first post and the time since members' first registration on the forum and subsequent posting. Contrarily, the number of replies received appears to mitigate subsequent posting.

Conclusions: Findings show posting activity on the forum to be concentrated in a minority of forum members who show posting trajectories that are both frequent and persistent. Results further suggest persistence in posting is motivated by social identity and, to a lesser extent, differential association processes.

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1. Introduction

Recent analysis of the correspondence of Edward Brongersma, who was a member of the Dutch Upper House between 1946 and 1960, and again between 1963 and 1977, and an evident advocate of adult-child sexual relationships, shows that Brongersma maintained an extensive and international correspondence network with like-minded individuals through which experiences and information on child sexual abuse were exchanged (Friedrichs, 2022). Likewise, German investigative journalist Manfred Karremann infiltrated several pedophile self-help groups in the early 2000s only to find that their members not only discussed their thoughts and feelings towards children, but also exchanged know-how on opportunities for child sexual abuse, and even collaboratively engaged in sexually molesting children (Karremann, 2007, cited in Von Lampe, 2016). While these examples show that community building among individuals with a sexual interest in children is not a new phenomenon (Harkins & Dixon, 2010; Jenkins, 2001), the exponential growth of the internet since 2005 enabled these communities to increase in size, as well as to extend their geographical range. At present, the darknet – the encrypted part of the internet that is to be accessed with The Onion Router (TOR) - offers those with a sexual interest in children access to hundreds of forums dedicated to 'child love' (IWF, 2023).

In many ways these darknet child sexual abuse material (CSAM) forums mirror mainstream forums on the clearnet, be it at a lower level of technical sophistication (Gannon et al., 2023). The landing page of a CSAM forum typically lists various "chat rooms" organized by topic, where forum members can openly discuss their sexual preferences and experiences, provide information, or ask questions to other forum members. This is also where links to CSAM material are shared with the community. Besides being marketplaces for CSAM, these darknet forums have been argued to provide for the validation of members' sexual preferences and identities, to contribute to normalization and neutralization of sexual child abuse, and to provide access to information and expert advice on both online and offline child sexual abuse (Kloess & van der Bruggen, 2023).

To serve forum users' "psychosocial and criminogenic needs in the most frictionless way" (Steel et al., 2023, p. 1) darknet CSAM forums, like mainstream forums, depend heavily on their membership generating content. In fact, active participation and a core of regular participants have even been argued to be prerequisites for speaking of an online community (Herring, 2004). As the quality and topicality of the material that can be accessed through a particular forum are deemed critical to online communities' popularity, growth and survival (Preece, 2001), questions with regard to users' motivations to contribute to online forums have been central to the study of online communities on more mundane topics (e.g. Jin et al., 2015; Mustafa et al., 2023). Many of these studies on mainstream forums take a data-driven approach to analyze the mechanisms behind members' contributing behavior. In contrast, empirical research on contributors' motivations to darknet CSAM forums is still scant and largely based on qualitative analyses of relatively small samples (e.g. Huikuri, 2023; Woodhams et al., 2021).

In this study we build on insights gained from research into clearnet knowledge sharing communities, and ask to what extent social dynamics highlighted by social identity, social exchange, and social learning theories can explain members' continued contribution to the CSAM forum. To answer this question, we make use of digital data on the online behavior of members of a darknet CSAM forum that was taken down by law enforcement in July 2015.

2. Why contribute to an online forum?

Studies into individuals' motivations to contribute to online forums have highlighted the various functions such postings may serve to those contributing. First, contributing to a forum may help individuals to establish their online identity, and present them as being part of a certain group (Postmes et al., 2005). Social identity theory suggests that individuals seek to present themselves in ways that signal membership of groups they deem worthy of emulation, for instance by the way they dress, speak, and behave. These cues, in turn, will make that others also allocate the individual to the desired group. In the online environment, contributing to a certain topic in a chat room of an online forum can help to convey individuals' group membership both for those posting as well as for others and thus aid to establish being part of the community's in-group (Kim et al., 2012). As such, the efforts involved in individuals' online representation may be taken to reflect individuals' desire to be part of the particular online community (Schwämmlein & Wodzicki, 2012).

Second, individuals may be enticed into continued contribution by the positive feedback they receive on their contributions from others in the community. Social exchange theory emphasizes reciprocity in social interactions (Hall, 2003). By replying to a post, the community fulfills posters' expectations on receiving a return on their initial investment, sustaining continued contribution (Li, 2015). Learning theory leads to a similar prediction stating that individuals tend to repeat actions that lead to positive reinforcement (Akers, 1973). Positive peer feedback affirms poster's acceptance by the group, providing the poster with a sense of recognition, belonging, and self-worth (Joyce & Kraut, 2006). Research on clearnet communities indeed shows that those that receive positive feedback on their contributions, are more likely to contribute in the future (e.g. Jin et al., 2015; Wang & Majeed, 2023).

Finally, forum contributions may also be triggered by processes of differential association. Observing other group members' online interactions will familiarize novice members with the behavioral norms of the community, and, to the extent that these norms favor politeness and reciprocity, provide individuals with positive definitions of contributing to the forum (Hsieh et al., 2013). Both the frequency and duration of individuals' differential associations are theorized to increase the likelihood of definitions being adopted (Sutherland, 1947). In addition, repeatedly witnessing the positive feedback other posters receive, provides novice members with ample opportunities for vicarious social learning (Miller & Morris, 2016).

Here, we examine the extent to which processes involved in social identity, social exchange, and social learning are associated with the period between CSAM forum members' forum contributions.

3. Prior research on CSAM forum participation

Typologies of online child sexual abuse offenders based on coagulated practical experience have highlighted the social dimension of CSAM offending, and typically link contact with like-minded others to heightened risk levels (e.g., Krone, 2004). In her study of a clinical sample of 110 adult, male CSAM offenders, McCarthy (2010) found that online contact with others sharing a sexual interest in minors was indeed predictive of having a history of contact offenses against minors. In contrast, using multidimensional scaling, Merdian (2012) distinguished a group of 'social users', who actively engaged with others interested in CSAM, but whose offending was confined to online offenses, and whose CSAM collections were less serious in nature. Due to the small overall sample size however, this 'group' consisted of only two individuals. Seigfried-Spellar (2014) found CSAM exchangers – those who engaged in online social interactions with other CSAM users – to be older and more extravert than those who did not engage in online interactions with other CSAM users, with extraversion interpreted as a facilitator of online contact. Again, the absolute number of 'exchangers' on which these conclusions were reached was low ($n = 3$). Of the 1546 respondents to an online self-report study among individuals who had searched for CSAM online, 42 % indicated to have had contact with other CSAM users, with 12.8 % reporting weekly contact (Insoll et al., 2022). In line with typologies associating social interaction to offense seriousness, those that reported contact with other CSAM users were more likely than those that did not to have engaged in seeking online contact with children.

Quayle and Taylor (2002, 2003) interviewed 13 men convicted of CSAM offending on the various functions contributing to an online CSAM forum can have. According to the interviewees, posting CSAM is a way of confirming ones sexual interests to others online. Sharing CSAM is meant to elicit exchange with other users. These men describe the online CSAM community as a hierarchical world, in which status can be achieved by providing rare or original CSAM material. Some of the interviewees also stress the social component of the CSAM community, describing the trading of CSAM as a means to perpetuate online relationships, rather than as an end in itself. Networking with other CSAM users may lead individuals to collect material that is outside of their own interest but deemed useful as currency in future interactions. CSAM production can likewise be seen in the context of networking and exchange (Quayle & Taylor, 2003).

The body of empirical research on the online behaviors of darknet CSAM forum members using digital forensic artifacts – system and user generated traces created during the use of computing technology that can be recovered from computing devices (Rogers et al., 2021) - is, at present, still scant. Van der Bruggen et al. (2022) analyze data on a darknet CSAM forum that had been active between August 2014 to March 2015. They find that only a small percentage (3.4 %) of forum members contributes messages to the forum. Yet, given the overall size of the forum under scrutiny ($N = 417,438$ users), in absolute numbers this percentage still pertains to well over 14,000 contributing members. Furthermore, during a two-week period the forum was actively monitored by a federal law enforcement agency, 93.6 % of the forum's members attempted to download material at least once. Despite refraining from contributing, the majority of forum members thus actively engages with CSAM. In another study, Van der Bruggen and Blokland (2022) describe the posting behavior of 14,838 posting members of a darknet CSAM forum that had been active between 2010 and 2014. They find that these members generated a total of 420,222 posts, but that the distribution of these posts across members was heavily skewed, with a minority of members having been responsible for the majority of posts. These authors distinguish seven developmental patterns in members posting behavior differing in the overall level of posting as well as in the temporal distribution of posts. Despite the study's longitudinal focus, due to data restrictions Van der Bruggen and Blokland (2022) were unable to assess the potential drivers of members' posting trajectories.

Da Cunha et al. (2020) utilize data gathered during a darknet sting operation in which the Brazilian Federal Police monitored the online activities of members of a darknet CSAM forum between 2014 and 2016. They find that 7.4 % ($n = 769$) of the forum's members are actively contributing CSAM to the forum, with the other 82.6 % only viewing the CSAM posted by others. Those that share CSAM, receive views from 1095 unique viewers on average, generating an average of 8208 views per post. Analyzing confiscated data on two large scale darknet CSAM forums, with memberships of 14,659 and 21,257 users respectively, Fonhof et al. (2019) find that abusers, defined as those communicating extensively about child sexual abuse, sharing experiences and fantasies, and potentially producing CSAM themselves or encouraging others to do so, constitute 0.6 % and 4.1 % of the forum's total membership respectively, and are among those most central to the forums' communication networks.

In sum, studies based on digital artifacts indicate that CSAM forum members differ in the extent they contribute to the forum, yet thus far have remained descriptive and silent on the possible drivers of these differences. To our knowledge, the present study will be the first study to empirically examine possible explanations for darknet CSAM forum members' contributions to the forum using digital artifacts.

4. The current study

The current study adds to the literature in at least two important ways. First, it extends the extant literature on online CSAM communities, and darknet CSAM forums in particular, by relying on a rich set of digital artifacts revealing detailed information on forum members' online behaviors to not just describe members' posting network and careers, but also examine the processes driving forum members' posting behavior. Second, by applying theories thus far only tested in research on mainstream online forums to darknet forums, the present study speaks on the generalizability of the theoretical and empirical insights gained in the workings of licit online communities to those of illicit online communities. While offline criminal networks are said to differ fundamentally from offline noncriminal networks due to the fact that the former need to function in a hostile environment (Morselli et al., 2007), the actual or perceived lawlessness of the darknet (Steel et al., 2023), may render darknet networks more similar to clearnet networks than are offline licit and illicit networks.

Based on prior research on both mainstream clearnet and darknet CSAM forums, we expect to find that public posting on the forum is heavily skewed, with many members not contributing, or contributing only few posts, whereas a minority contributing frequently is responsible for the majority of all posts. This skewness, in turn, is reflected in the results of both group-based trajectory models and social network analysis. Specifically, we expect:

H1. Various posting trajectories based on the frequency and timing of posts can be distinguished, with a minority of members following a posting trajectory characterized by frequent and persistent posting.

H2. The posting network is more centralized than expected by chance, with few members being highly central to the network.

Moreover, we operationalize the efforts involved in individuals' online representation as the length of the individual's introductory post to the forum. Based on social identity theory we expect that individuals' online representation reflects their desire to be part of the forum community. Hence, our third hypothesis reads:

H3. The length of members' first post to the forum is negatively associated with the time between their subsequent postings.

Based on social exchange theory, we expect members' posting behavior to be susceptible to positive feedback from the community. Within the context of the online forum, positive feedback is defined as the number of positive replies individuals receive on their posts. This leads to our fourth hypothesis:

H4. The number of positive replies to a member's present post is negatively associated with the time until this member's subsequent posting.

Finally, to test notions central to differential association and social learning theories, we take the time since becoming a member to the forum as a proxy for the frequency of exposure to behavioral norms regarding reciprocity in the context of sharing CSAM material.

H5. The amount of time since member first registered to the forum, is negatively associated with the time between their subsequent postings.

5. Materials and methods

5.1. Darknet CSAM forum

The current study uses digital data on a CSAM forum active on the darknet between February 2015 and July 2015, when the forum was taken down by law enforcement agencies. The forum advertised itself as a 'child love' forum, banning materials such as hurtcore, rape, and penetrative sex involving children under the age of five. During the period the forum was online, it accumulated 1146 registered members, generating over 40 messages per day on average. When the forum was taken down, law enforcement agencies confiscated the entire backlog of the forum, providing a data base of digital forensic artifacts allowing for the detailed reconstruction of member activity on the forum. The current analyses focus on members' activity on the public part of the forum where members can post messages and react to messages posted by others.

5.2. Operationalizations

Posting refers to a member contributing a message to the public part of the forum. We differentiate between two categories of posts: original posts, these are posts that are not a reply to a post contributed by another member, and replies, which are reactions posted in response to other members' postings. Original posts and replies were identified based on the message title; replies starting with 'RE:' followed by the title of the post the reply was on. Since original posts sharing CSAM are likely to generate more replies than original posts that do not, we differentiate between the two based on whether a post contained a hyperlink. Due to the historical nature of the data the actual content of the hyperlink could no longer be ascertained. Manual analysis of a random sample of 500 posts containing hyperlinks, however, showed that the text included in 478 (95.6 %) of these directly referred to CSAM, typically describing the name, age or sex of the victim, and/or the nature of the sexual acts depicted. Of the 22 messages that did contain a link, but did not directly refer to CSAM, 11 directly referred to other forums or chat sites where CSAM was made available. Hence, we conclude that for the purpose of our current analysis the presence of a hyperlink is a valid proxy for sharing CSAM on this particular forum.

Self-presentation was operationalized as the number of characters in the introductory post of a particular member, with longer introductory messages taken as indicative for higher levels of self-presentation. Based on social identity theory and prior research on clearnet forums, we expect higher levels of self-presentation to be associated with shorter intervals between members' forum posts.

Peer feedback was measured by the number of reply messages members received on the messages they themselves posted. Positive reinforcement contributes to behavioral persistence, while peer feedback may also quench members' need to belong to the online CSAM community. For these reasons we hypothesize that higher levels of positive peer feedback promote continued posting. Manual assessment of a random sample of 500 replies indicated that 380 (76.0 %) could be labeled 'encouraging', and 118 (23.6 %) as 'neutral'. The latter typically pertained to requests for re-uploading material (e.g. "please re-up"; "download down?"), which, despite the neutral wording of the reply, was taken as signaling interest in the material. Two sampled replies were framed 'negative' but were directed at the forum policy of not allowing material depicting under five-year old victims, rather than at the individual poster. Therefore, for the purpose of this analysis all replies were counted as positive feedback.

Differential association was measured by the time members were registered on the forum. In case the date of registration was

unknown (20.1 % of all members; 47.4 % of posting members), it was replaced with the date of the member's first post. Many darknet CSAM forums are characterized by an open, welcoming, and polite atmosphere (van der Bruggen & Blokland, 2021). The forum analyzed here being no exception. In fact, the rules of the forum state in so many words that "hate speech" or "abuse of other members" is not allowed. Based on the principles of differential association and social learning, increased exposure to the forum environment was expected to be associated with persistent posting.

5.3. Analytic approach

To test H1, and following prior research on the posting sequences of members of darknet CSAM forums (van der Bruggen & Blokland, 2022), we use group-based trajectory modelling (GBTM) to summarize the course of members' posting 'careers'. For details on GBTM see: Nagin (2005). Here, GBTM serves the purpose of summarizing the posting data in a limited number of distinct trajectories. To the extent that these trajectories not only differ in level, but also in shape, we see this as a first hint that dynamic processes are driving members' posting behavior (Skardhamar, 2010).

We then use social network analysis to construct the directed communications network underlying the forum, with nodes representing posting members, and arcs representing replies to original posts. This allows us to calculate node characteristics, such as the number of incoming and outgoing arcs (indegree and outdegree centrality), but also metrics that refer to the entire network, such as density and centralization. Density refers to the percentage of potential links that is observed in the network and reflects the level of network cohesion. Centralization refers to the distribution of the nodal centrality across the network and describes the extent to which network cohesion is organized around one or more focal points. Estimating a series of random networks with the same predefined number of nodes and arcs allows us to estimate the likelihood the observed network centralization could have occurred by chance providing a test of H2.

To analyze the predictive value of forum social dynamics on members' posting (H3–H5), we estimate a series of mixed-effect survival models. The dependent variable in the current analyses is the time until the subsequent post. As members can, and do, have multiple posts during the time the forum was live, our data concerns repeated events. Mixed-effect survival models are particularly suited for analyzing longitudinal data with repeated events as they control for the nesting of events within individuals (Skrondal & Rabe-Hesketh, 2004). The proportional-hazards mixed-effects survival model estimated here reads:

$$h(t_{ji}) = h_0(t_{ji}) exp(x_{ji}\beta + z_{ji}u_j)$$

for $j = 1, \ldots, M$ members, with for each member j $I = 1, \ldots, n_j$ posts. In the above model $h_0(t)$ is the baseline hazard function, whereas x_{ji} and z_{ji} represent covariates corresponding to the fixed and random effects respectively. If $z_{ji} = 1$ for all j and i, then the model reduces to a random-intercept or shared frailty model (Crowther, 2019). Here, we fit Weibull models with random effects at the member level using the *mestreg* function in Stata 15.

6. Results

6.1. Forum and member-level descriptives

During the nearly six months the forum was online, 1146 individuals registered as forum members, of which 462 (40.3 %) actively participated in the online community by posting on the public part of the forum. In total, members posted 6772 posts, of which 23.8 % ($n = 1613$) were original posts, and 76.2 % ($n = 5159$) were replies to the original posts of others. Of the original posts 56.2 % ($n = 906$) contained a hyperlink. The development of forum activity over the period the forum was online is depicted in Fig. 1. Both the number of original posts (with and without a hyperlink), and the number of replies reaches a peak during the first two-and-a-half months the
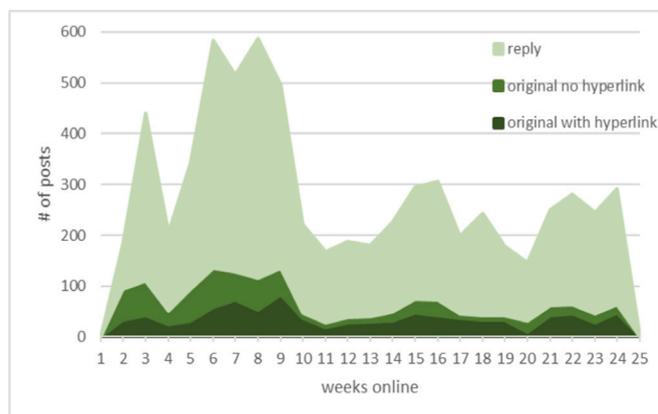

Fig. 1. Number of posts per week the forum was online by post type.

forum is online, after which levels of forum activity drops of to 228 posts per week on average. The number of posting members also fluctuates over time (Fig. 2). During the first weeks the forum is online the number of members posting posts without a hyperlink trumps that of members posting posts with a hyperlink, but as the forum evolves this pattern is reversed. Also, the development of the number of members posting replies mirrors that of the number of replies posted, suggesting that peaks in the number of replies result from more members replying, rather than from the same number of members more frequently posting replies.

Of all posting members, 77.9 % ($n = 360$) posted at least one original post, and 84.4 % ($n = 390$) posted at least one reply. Of all posting members, 15.6 % ($n = 72$) posted original posts yet never replied to the posts of others, whereas 22.1 % ($n = 102$) only replied to the posts of others, leaving 62.3 % ($n = 288$) of members both initiating and continuing online conversation (Table 1). Of members contributing original posts, 44.7 % ($n = 161$) contribute at least one post containing a hyperlink. As shown in Table 2, for both original posts and replies the average number of posts per member is less than its median which suggests the distribution of posts is skewed to the right. The boxplots in Fig. 3 depict the observed distribution of original posts with hyperlinks, original posts without hyperlinks, and replies across members; indeed all evidence a right skew which is a first indication that a small number of forum members is disproportionately active in the online community.

6.2. Members' posting trajectories

Using the CrimCV package in R, we then estimate GBTMs up to five groups using third degree polynomials to model variation in posting frequency with time, while binning posts in weekly amounts per member based on their Unix timestamp. By way of sensitivity check, we also estimated GBTMs with quadratic polynomials. As with the cubic models, CVEs (cross-validation errors) for these models indicate a 3-group model as optimal. Unlike previous analyses applying GBTM to darknet CSAM forum data, here we take the first week the forum was online as the starting point for all trajectories. In doing so, we make the onset of posting a distinguishing dimension, similar to the frequency, acceleration, and de-acceleration of posting. Based on the resulting CVEs (Nielsen et al., 2014), posterior probabilities of group membership, resulting group sizes and odds of correct classification (Nagin, 2005), we find that the 3-group group model provides the best fit to the data (see Tables A1 and A2 in the Appendix). Resulting trajectories are depicted in Fig. 4. In concordance with H1, the three-group model distinguishes a group whose posting frequency is higher than that of the other two groups, and that stays high during the entire period the forum was online. The estimated posting frequency for group 1 structurally overestimates the average observed posting frequency for members allocated to this group. Visual inspection of the observed posting frequencies for individual members suggests that this is likely due to outliers in the observed data. This does however not negate our conclusion that a group of highly active members can be distinguished on the basis of the posting data. Fig. 5 depicts the contribution of each of the groups distinguished in the GBTM analysis to the public communication on the forum for each consecutive week between February and July 2015. From Fig. 5 it becomes clear that, after a period of heightened activity during the first ten weeks of the forums existence, communication on the public part of the forum is increasingly dominated by a small group of frequently posting members.

6.3. The forum's public reply network

Next, we turn to social network analysis to examine the patterning of forum members' replies. The reply network is visualized in Fig. 6, such that bigger nodes represent members who post more replies (outdegree), and darker colored nodes representing those that receive more replies (indegree). Arcs representing less than five replies have been suppressed for visual clarity. Fig. 6 reveals a core of a limited number of active members sending and receiving the majority of all replies. Still, while some who send a lot of replies (larger nodes) also receive a lot of replies (darker nodes), there are also members who disproportionately send or receive replies. One node in particular receives a lot of replies, without sending any itself. Table 3 provides the observed indegree and outdegree centralization of the forum's reply network for the overall posting network. The latter four columns represent the minimum, average, maximum and standard deviation of these measures based on 10,000 permutations. Indegree centralization is higher than outdegree centralization in
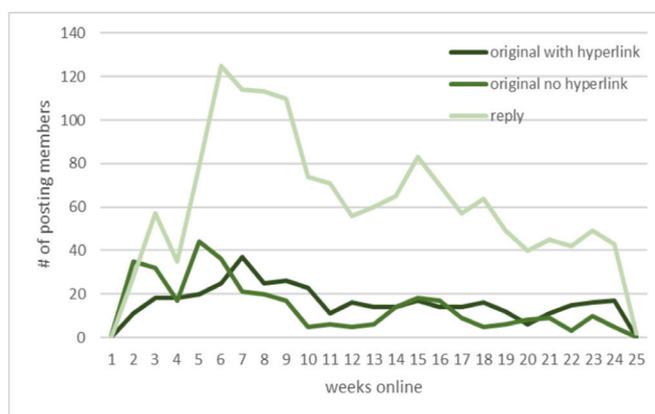

Fig. 2. Number of posting members per week the forum was online by post type.

Table 1
Number of posting members by post type.

		Reply		Total
		No	Yes	
Original post	No	0	102	102
	Yes	72	288	360
	Total	72	390	462

Table 2
Number of posting members and mean, median and range of posts per member per post type.

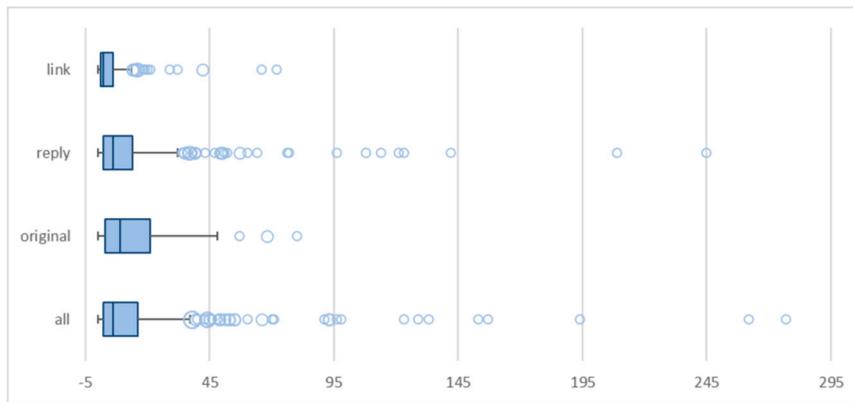|	# members	Mean # posts Per member	Median # posts Per member	Range # posts Per member
All posts	462	14.66	20	1–277
Original posts	360	4.48	2	1–80
Replies	390	13.23	6	1–245
Original posts with link	161	5.63	2	1–72

Fig. 3. Distribution of original posts with hyperlink, original posts without hyperlinks and replies across forum members.
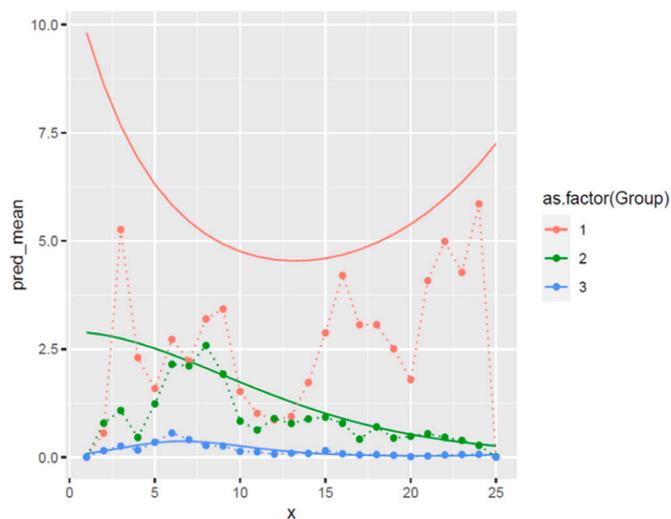

Fig. 4. Observed and predicted mean number of posts per week for three groups of forum members distinguished by GBTM.
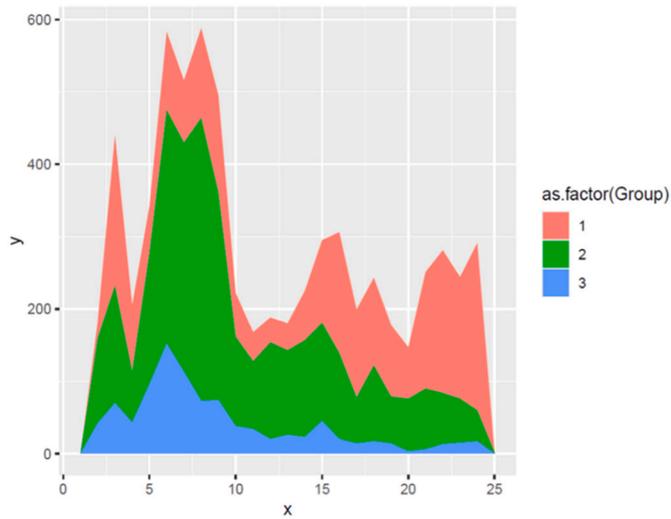
Fig. 5. Posting per week for different groups of forum members across the period the forum was online.
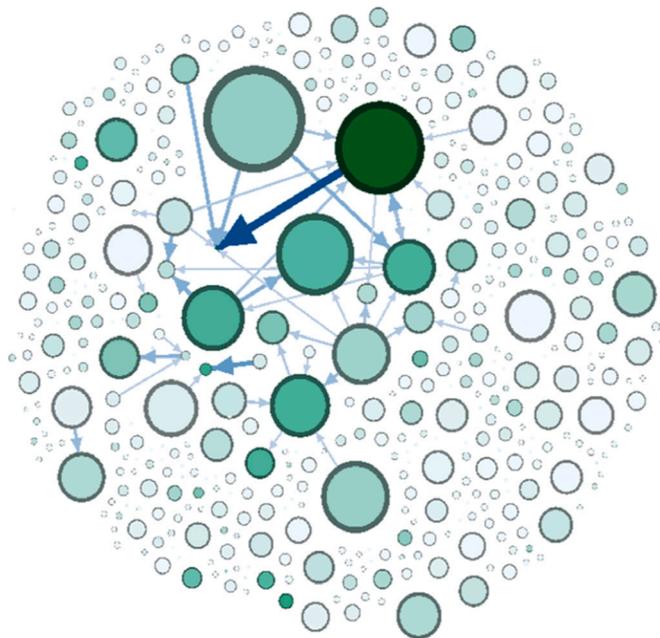
Fig. 6. Visualization of the forum's reply network with node size based on the number of replies received (indegree), and node color based on the number of replies send (outdegree) with darker nodes sending out more replies. Edges are weighted by the total number of replies between nodes, with ties representing five or less replies suppressed for visual clarity.

Table 3
Indegree and outdegree centralization for the observed reply network, and based on 10.000 permutations.

	Observed	Based on 10,000 permutations				
	Centralization	Minimum	Average	Maximum	St. dev.	*p* (two-tailed)
Indegree	0.2044222	0.0154013	0.02486810	0.0459021	0.003468279	< 0.001
Outdegree	0.1392051	0.0154013	0.02493237	0.0459021	0.003502909	< 0.001

Table 4a
Results from the multi-level repeated events survival models (all posts).

	Model 1					Model 2					Model 3					Model 4				
	Hazard ratio	Sign.	Ste	95 % conf. int.		Hazard ratio	Sign.	Ste	95 % conf. int.		Hazard ratio	Sign.	Ste	95 % conf. int.		Hazard ratio	Sign.	Ste	95 % conf. int.	
Length first post	1.001	***	0.000	1.000	1.002	1.001	***	0.000	1.000	1.002	1.001	***	0.000	1.000	1.002	1.001	***	0.000	1.000	1.002
# Replies latest post						0.978	***	0.007	0.965	0.992	0.966	***	0.009	0.948	0.985	0.978	**	0.009	0.961	0.997
# Prior posts											1.016	***	0.003	1.010	1.022	0.991	***	0.004	0.984	0.998
# Replies*# prior posts											1.002	**	0.001	1.000	1.003	1.003	***	0.001	1.001	1.004
Time since registration/first post																1.020	***	0.002	1.017	1.023
#Replies* time since registration																0.998	***	0.000	0.998	0.999
Constant	0.002	***	0.000	0.001	0.003	0.002	***	0.000	0.001	0.003	0.003	***	0.001	0.002	0.005	0.004	***	0.001	0.003	0.007
/ln_p	−1.004		0.028	−1.059	−0.949	−1.002		0.028	−1.057	0.947	−1.110		0.034	−1.177	−1.044	−1.181		0.036	−1.251	−1.111
Member																				
Var (constant)	3.651		0.487	2.811	4.742	3.756		0.502	2.890	4.882	3.350		0.462	2.556	4.389	3.286		0.448	2.515	4.293
LR versus Weibull Chi^2	2519.08	***				2530.60	***				1223.70	***				1250.03	***			

* = p < 0.1; ** = p < 0.05; *** = p < 0.01

Table 4b
Results from the multi-level repeated events survival models (only posts with hyperlink).

	Model 1					Model 2					Model 3					Model 4				
	Hazard ratio	Sign.	Ste	95 % conf. int.		Hazard ratio	Sign.	Ste	95 % conf. int.		Hazard ratio	Sign.	Ste	95 % conf. int.		Hazard ratio	Sign.	Ste	95 % conf. int.	
Length first post	1.001		0.000	1.000	1.001	1.001		0.134	1.000	1.002	1.001		0.130	1.000	1.002	1.001		0.000	1.000	1.001
# Replies latest post						0.928	***	0.012	0.905	0.951	0.903	***	0.015	0.873	0.934	0.948	***	0.017	0.914	0.982
# Prior posts											1.005		0.004	1.001	1.004	0.970	***	0.005	0.961	0.980
# Replies*# prior posts											1.002	***	0.001	1.001	1.004	1.001		0.001	0.999	1.004
Time since registration/first post																1.026	***	0.002	1.022	1.030
#Replies* time since registration																0.999	**	0.000	0.998	1.000
Constant	0.001	***	0.000	0.001	0.002	0.002	***	0.001	0.001	0.003	0.003	***	0.001	0.002	0.006	0.003	***	0.001	0.001	0.005
/ln_p	−0.844		0.037	−0.916	−0.772	−0.864		0.038	−0.937	−0.790	−0.929		0.046	−1.018	−0.840	−0.992		0.047	−1.084	−0.900
Member																				
Var (constant)	2.744		0.486	1.939	3.883	2.757		0.490	1.946	3.906	2.614		0.474	1.832	3.731	2.930		0.514	2.076	4.133
LR versus Weibull Chi^2	1262.04	***				1241.51	***				728.99	***				798.91	***			

* = p < 0.1; ** = p < 0.05; *** = p < 0.01

both reply networks which means that fewer members are receiving a lot of replies, whereas sending replies is less focused around a limited number of active members. Obtained permutation results furthermore suggest that the observed network is significantly more centralized than would be expected by chance given a network of the observed size and density. The results from the network analysis thus corroborate the descriptive results in Fig. 3 in finding that contribution to the forum – here in terms of replies to original posts - is heavily skewed.

Finally, to test for the social dynamics driving posting behavior (H3–H5), we estimate a series of mixed effect survival models. We estimate Weibull models. p is the shape parameter estimated from the data. When $p = 0$ (as it is in our case ($\exp(-1,0004) = 0$), the hazard function is equal for all t, so the model reduces to an exponential model.

These models pertain to the 360 forum members who contributed at least one original post to the forum. Together, these members generate 1613 observations, of which 360 are right censored due to forum take down. To test the extent to which the length of members' first post to the forum is negatively associated with the time between subsequent postings (H3) we estimate a shared frailty model including a random intercept at the individual level to capture any latent member effects, regressing time between original posts on the number of characters in members' first post (model 1, Table 4a). The likelihood-ratio test compares the random-effects model with a survival model with fixed-effects only. The results support the random-effects model. We find that the exponentiated coefficient for length of the first message posted is 1.001. While the exponentiated coefficients of time-stable variables do not have a natural interpretation as conditional hazard ratios, their magnitude is nevertheless informative. Here, the value of 1.001 indicates that the hazard functions for those with longer introductory messages tends to be higher than that for those whose first message posted on the forum is shorter. Model 2 adds the number of replies to a member's latest post as a predictor of the time difference between that latest post and the next (H4). Results from model 2 show that the conditional hazard ratio for the number of replies, of which the value does change with each subsequent post, is 0.978. This means that for every additional reply received, the hazard decreases by 2.2 %. Model 3 adds an interaction between the number of previous posts posted by a particular member and the number of replies received on that member's latest post allowing for either an increase or decrease in the association between the number of replies and the time difference between subsequent posts. Results obtained from model 3 suggest that the association between the number of replies received and continued posting is mitigated by the posters' posting history, with those whose previous activity on the forum is more extensive being increasingly less susceptible to forum feedback. Finally, we add a variable indicating the time in days a particular member has been registered as a member of the forum to the model to allow for effects of differential association (H5, model 4). We find that time since first registration is associated with an increase in the hazard of continued posting.

We repeated the above analysis only selecting posts that contained a link. Results from these models are provided in Table 4b. These models pertain to 160 members together generating 905 observations of which 160 are right-censored due to forum take-down. Results from the analysis only taking into account posts that contain a hyperlink closely mirror those found for all posts, accept that the length of the first post no longer significantly predicts the time between subsequent postings (H3).

7. Discussion

The anonymity provided by the darknet has given rise to online communities of individuals interested in CSAM. Besides digital market places providing access to CSAM, forums dedicated to 'child love' perform important social functions for their membership. Building on prior research on clearnet forums, for the first time the present study examined the social dynamics on a darknet CSAM forum using digital artefact data.

Confirming expectations laid down in our first hypothesis, various posting trajectories could be identified that differed both in overall level and in shape. The latter suggesting that, besides stable individual differences, dynamic processes are driving CSAM forum contribution. In accordance with prior findings on both clearnet and darknet forums (e.g. van der Bruggen et al., 2022; van der Bruggen & Blokland, 2022), we find that the majority of the communication on the darknet CSAM forum under scrutiny, is generated by a minority of disproportionally active members. For this particular forum, we also find that, over time the activity of these highly active members becomes increasingly important to the persistence of forum community. In line with our second hypothesis, we find that the reply network generated by forum members' reactions to other members posts is centralized, indicating a core of central members generating a large share of the total community feedback. Corroborating the expectations based on social identity theory of our third hypothesis, we find that the length of members' first post, which we interpret as a proxy for self-presentation, is positively associated with continued contributions to the forum. This result matches qualitative studies finding that contributing to darknet CSAM forums is a way of confirming ones sexual interests to others online (Quayle & Taylor, 2002, 2003). Unexpectedly, and contrary to the expectation based on social exchange theory laid down in our fourth hypothesis, we find that the number of replies received on a particular post reduces the hazard of subsequent posting. While at this point, we can only speculate why this is the case, it might have to do with the nature of the CSAM material posted. Assuming that high quality original footage depicting certain types of victims and certain types of sexual acts is most appreciated within the community (Owens et al., 2023) – thus generating the most feedback –, constraints to generating this type of footage may prevent members from repeatedly posting such material, or at least result in larger time intervals between posts. Finally, and in line with our fifth hypothesis, time since registration on the forum was positively associated with subsequent posting, corroborating the notion that prolonged exposure to the forum environment, increased members' desire and/or lowered members' barriers to contributing.

A number of caveats apply when interpreting these results. We currently have no way to ascertain the extent to which the current findings generalize to darknet CSAM forums besides the one under scrutiny. While some findings, like finding a core of active members, corroborate prior findings on both clearnet and darknet forums, particularly additional research into the social dynamics of darknet CSAM forums is warranted to be able to draw definitive conclusions. Furthermore, directly comparing different types of darknet

forums with clearnet forums may speak to the extent to which these social dynamics are influenced by the illicit context of darknet marketplaces.

Compared to other darknet CSAM forums analyzed in the academic literature, in terms of registered membership the current forum was relatively small, and the observation period limited. As increased length of observation may also increase momentum for the social processes examined here, future research should seek to replicate the current findings on larger forums, that were active for longer periods of time. More generally, both research and practice would benefit from a systematic comparison of darknet CSAM forums on a number of core features to provide the foundation for future knowledge enhancement.

The rather coarse operationalizations used in the current analyses could also be refined in future efforts. For instance, follow-up studies may want to employ linguistic methods to identify specific cues. relevant to self-presentation in members' first posts other than its overall length (Joyce & Kraut, 2006). Likewise, the time members were actually logged on to the forum would constitute a better proxy for members' exposure to the forum's normative environment. Importantly, the current analyses were based on the public part on the forum. Many darknet CSAM forums also offer members the opportunity for one-on-one interaction in private chats. These private chats may give rise to personal relationships between members of which the social dynamics may add to those observed on the forum level, for instance identification with the community versus the desire for online friendship with a certain fellow member, or generalized reciprocity versus individualized reciprocity in the context of a dyadic relationship. Future research therefore should seek to include private messaging.

Notwithstanding these caveats, the current study yields some important insights into the social dynamics of a darknet CSAM forum. From a law enforcement perspective, members actively contributing CSAM to the forum represent key targets for intervention. Given that, as on the clearnet, member activity on CSAM forums tends to follow a power law, investigative capacity should be directed to those on the highest trajectory and most central to the forum's communication network. Clinically, the finding that social dynamics, in part, drive forum contributions, not only signals that darknet CSAM forum members' behavior is susceptible to outside influence, but also that participation in these communities might be driven not solely by individuals' sexual interest in children, but fulfills certain social needs as well (Quayle & Taylor, 2003). Confronted with clients convicted of online CSAM offending, clinicians might explore alternatives to darknet CSAM forum membership to meet individuals' need for recognition and social interaction that do not constitute sexual offending. Given the investigative and clinical relevance of those contributing CSAM to darknet forums, the present analyses focused on the social processes driving members' posting behavior. However, those socializing newly registered members into the community, and encouraging others to upload CSAM to the forum, might be as important to the forum's survival, and therefore to law enforcement, than those posting CSAM themselves. Hence, future research might also want to focus on members' motivations for replying to others (Hsieh et al., 2013).

Finally, in its latest report the Internet Watch Foundation observes a rising trend in the number of commercial hidden services dedicated to CSAM (IWF, 2023). Of the 1067 darknet CSAM websites newly identified in 2022, 79 % ($n = 848$) were offering CSAM material for sale. Commercial activity on (parts of) a darknet CSAM forum is likely to impact community dynamics and members' motivations to contribute. Given the continuously changing nature of the online environment, and with it the opportunities and incentives for sharing CSAM online, continued research on darknet CSAM forums remains warranted.

CRediT authorship contribution statement

Arjan Blokland: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Anton Daser:** Writing – review & editing, Conceptualization. **Meike de Boer:** Writing – review & editing, Conceptualization. **Colm Gannon:** Writing – review & editing, Conceptualization. **Frederic Gnielka:** Writing – review & editing, Conceptualization. **Salla Huikuri:** Writing – review & editing, Conceptualization. **Rebecca Reichel:** Writing – review & editing, Conceptualization. **Thomas Shäfer:** Writing – review & editing, Conceptualization. **Alexander F. Schmidt:** Writing – review & editing, Conceptualization. **Katarzyna Staciwa:** Writing – review & editing, Conceptualization. **Robert Lehmann:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors report there are no competing interests to declare.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chiabu.2024.106815.

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