Problematic smartphone use and the quantity and quality of peer engagement among adolescents: A longitudinal study

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ABSTRACT

Problematic smartphone use (PSU) has recently attracted a lot of attention, especially among adolescents. The knowledge about the role peer engagement might play in the development of PSU is still limited. We aimed to investigate the bidirectional relationships between PSU, the quantity of online (i.e., passive and active social media messaging on smartphone) and offline peer engagement (i.e., intensity of face-to-face meeting with friends) and the quality of peer engagement (i.e., perceived competence in close friendships) among adolescents. Data from a three-wave longitudinal study among 2100 Dutch high school students (56.7% boys) was used. Cross-lagged models indicated that: (1) perceived competence in close friendships at T1 negatively predicted PSU at T2 and PSU at T2 negatively predicted perceived competence in close friendships at T3; (2) there were positive and reciprocal cross-lagged correlations between PSU and passive social media messaging on smartphone; (3) there were positive and reciprocal cross-lagged correlations between intensity of face-to-face meeting with friends and active social media messaging on smartphone. This implies that adolescents who perceive a low competence in close friendships and/or intensively check their smartphone for messages from their peers may be particularly vulnerable to developing problematic smartphone use over time.

1. Introduction

During the past decade, smartphone use has strongly increased and is considered a necessary element of everyday life (Y. Kim, Wang, & Oh, 2016; Kuss et al., 2018; Recio-Rodriguez et al., 2019). In parallel, problems related to smartphone use have increasingly been reported. There is increasing evidence that excessive smartphone use can negatively affect mental (e.g., higher levels of depression and anxiety; Elhai, Levine, O'Brien, & Armour, 2018; Elhai, Yang, Fang, Bai, & Hall, 2019) and physical health (e.g., neck problems, poor sleep quality; AlAbdulwahab, Kachanathu, & AlMotairi, 2017; Demirci, Akgönül, & Akpinar, 2015). In previous studies, problematic smartphone use (PSU) has been defined as a persistent and excessive pattern of smartphone use accompanied by significant impairments in daily-life functioning, and the impairments could include daily-life disturbance, positive anticipation, withdrawal, cyberspace-oriented relationship, overuse, and tolerance (Kardefelt-Winther et al., 2017; Kwon, Lee, et al., 2013). We used this proposed definition in the current study and the most popular

instrument measuring PSU-the short version of smartphone addiction scale (SAS-SV) was developed for adolescents based on such a definition, which has been validated across different countries (Kwon, Kim, et al., 2013; Kwon, Lee, et al., 2013; Luk et al., 2018). Note that the symptoms of PSU proposed in previous research are similar to the established criteria of substance use disorders in DSM-5 (APA, 2013; Kwon, Lee, et al., 2013; Lin et al., 2016), and the question whether PSU should be considered as a behavioral addiction is still heavily debated (Elhai & Contractor, 2018; Horvath et al., 2020; Körmendi, Czki, Végh, & Székely, 2016; Panova & Carbonell, 2018). Adolescents are thought to be particularly susceptible to develop PSU (Fischer-Grote, Kothgassner, & Felnhofer, 2019; Sohn, Rees, Wildridge, Kalk, & Carter, 2019) because of their suboptimal self-regulation and lack of control competencies (see a review, Fischer-Grote et al., 2019; H. J. Kim, Min, Min, Lee, & Yoo, 2018). Hence, it is vital to explore the underlying pathways of adolescents' problematic smartphone use (PSU).

Based on previous studies, PSU has been associated with adolescents' personality characteristics (e.g., conscientiousness, openness and

neuroticism; Cocoradă, Maican, Cazan, & Maican, 2018), relatively poor self-control (H. J. Kim et al., 2018), and to mental health (e.g., depression, anxiety; S.-G. Kim et al., 2019). Regarding environmental factors, PSU has been related to parental factors (e.g., democratic parenting and psychological abuse; Bae, 2015; Sun, Liu, & Yu, 2019) and peer factors (e.g. the relationship between students and their classmates; Y. Wang et al., 2017). Both peers and parents play an important role in the socialization process of adolescents (Lakon et al., 2015). Nevertheless, peer may be a more salient factor since the effects of parents gradually decrease during adolescence (Huang et al., 2014). Besides, autonomy, competence, and relatedness are the basic needs for adolescents according to self-determination theory and their need for relatedness could be fulfilled by peer engagement, which also makes it necessary to investigate the effects of peer engagement (Ryan & Deci, 2017; Vasconcellos et al., 2020). The term peer engagement refers to social interactions with peers, including the investment in peer interaction, as well as the formation, maintenance of peer relationships (Scanlon, Del Toro, & Wang, 2020; M. T. Wang & Hofkens, 2020). Peer engagement plays a complex but important role in adolescents' development of other problematic behaviors like the use of cigarettes, alcohol (Huang et al., 2014; Van Ryzin, Fosco, & Dishion, 2012). Only limited studies have investigated the potential role of peer engagement in the development of PSU and longitudinal studies are still missing. Given the popularity of social media messaging among adolescents (Dolev-Cohen & Barak, 2013; Huang et al., 2014), the crucial role it nowadays plays in the maintenance of social relationships (see a review, Spies Shapiro & Margolin, 2014), and the influences of choosing online social media messaging as a preferred communication way (Caplan, 2003), it is important to consider the role of online peer engagement as well as offline peer engagement, both in quantity and quality.

In terms of online peer engagement, social media messaging is now the main tool for adolescents to contact with their peers with the technology development (Dolev-Cohen & Barak, 2013). The relationship between social media messaging on smartphone and PSU could be bidirectional based on existing findings (Haug et al., 2015; Rozgonjuk, Saal, & Täht, 2018; Van Deursen, Bolle, Hegner, & Kommers, 2015), while the strength of active (e.g., sending pictures or messages) and passive (e.g., checking pictures or messages) social media messaging with PSU can be expected to differ based on the evidence from previous studies (Allegrante & Sigfusdottir, 2019; Kross et al., 2013; Verduyn, Ybarra, Résibois, Jonides, & Kross, 2017). For example, Allegrante and Sigfusdottir (2019) found that active (e.g., posting pictures, sending messages, etc.) and passive (e.g., scrolling profiles, checking messages, etc.) social media use were highly related, but higher frequency of active social media use was related to lower emotional distress (i.e., symptoms of anxiety and depressed mood) and higher frequency of passive social media use was related to higher emotional distress among adolescents. Based on existing findings, we propose Hypothesis 1 (H1): there are bidirectional positive associations between PSU and both active and passive social media messaging on smartphone, and the relationship between PSU and passive social media messaging on smartphone is stronger than the relationship between PSU and active social media messaging on smartphone.

Regarding real-life, offline peer engagement, the relationship between the quantity of offline peer engagement (i.e., intensity of face-to-face meeting with friends) and PSU is currently unclear. There is a possibility that adolescents' PSU might positively relate to intensity of face-to-face meeting with friends, since adolescents might use smartphones to gain peer acceptance and peer conformity when they meet with their friends who use smartphones excessively (Lee & Lee, 2017). However, it is hard to speculate the strength of this pathway because of prevalence of smartphone use problems differs from 5% to 50% among children and adolescents (see a review, Fischer-Grote et al., 2019). In contrast, adolescents' PSU could also negatively relate to intensity of face-to-face meeting with friends, as intensity of face-to-face meeting with friends might be an indirect protective factor for PSU (Caplan,

2003; M. T. Wang and Hofkens, 2020). Based on the two different rationales and limited evidence, we do not formulate specific hypotheses on the direction of the relationship between intensity of face-to-face meeting with friends and adolescents' PSU though we think the association exists.

An important indicator for quality of peer engagement is perceived competence in close friendships (Scanlon et al., 2020; M. T. Wang & Hofkens, 2020; Yoder, Williford, & Vitiello, 2019). Perceived competence in close friendships refers to the capabilities to develop and sustain close friendships, which is significant for adolescents' socioemotional adjustment (Bornstein, Hahn, & Haynes, 2010; Buhrmester, 1990). It pertains to both online and offline peer engagement. In previous studies, poor social competence has been found to be a risk factor for the development of many problem behaviors like pathological gaming (Lemmens, Valkenburg, & Peter, 2011; Peeters, Koning, & van den Eijnden, 2018). Adolescents who perceive low social competence would use online interactions as alternatives for face-to-face interaction. Their preferences for online interactions might lead to more problematic smartphone use (Caplan, 2003). Not only can competence in close friendships negatively predict PSU, PSU could also negatively impact adolescents' perceived competence in close friendships since excessive smartphone use may interfere with in-person social interactions, thereby creating a negative downward spiral (Przybylski & Weinstein, 2013; Rotondi, Stanca, & Tomasuolo, 2017). Thus, we posit Hypothesis 2 (H2): there is a bidirectional negative association between perceived competence in close friendships and PSU.

Adolescents tend to use social media messaging on their smartphone to also promote and strengthen connections with their friends (Davies, 2014; Davis, 2012; Nesi, Choukas-Bradley, & Prinstein, 2018). For instance, instant messaging has been demonstrated to be positively linked to adolescents' perceived quality of peer interactions (Floros et al., 2015). Social media messaging also provides meeting opportunities when in-person meetings are not feasible, which could, in turn, facilitate the quality of in-person offline relationships (Davies, 2014). Social media messaging on smartphone during in-person social interactions, however, could also be intrusive, impairing friendship quality (Hales, Dvir, Wesselmann, Kruger, & Finkenauer, 2018; Noë et al., 2019; Przybylski & Weinstein, 2013; Rotondi et al., 2017). Social media messaging on smartphones might therefore both disturb or facilitate adolescents' social interactions (Allen, Ryan, Gray, McInerney, & Waters, 2014). Therefore, the relationships between online (i.e. active and passive social media messaging) and offline peer engagement (i.e., intensity of face-to-face meeting with friends) and the quality of peer engagement (i.e., perceived competence in closed friendships) were also tested in current study.

1.1. This study

Previous studies suggest an important, but complex relationship between quantity and quality of peer engagement and PSU. Little is still known about their relationship over time, taking bidirectional relationships into account. The goal of the current study, therefore, was to investigate the bidirectional associations between the quantity and quality of peer engagement and PSU over time, in which we considered active and passive social media messaging on smartphone, intensity of face-to-face meeting with friends and perceived competence in close friendships. We investigated the longitudinal bidirectional associations with 3 measurement waves in a large sample of adolescents between 10 and 16 years old.

Structural equation modeling (SEM) with three-wave longitudinal data was applied to estimate the cross-lagged models. This study will also test the possible confounding roles of several covariates. According to Social Learning Theory (Bandura & Walters, 1977), children may learn from parents through observing and imitating parental behavior. Regarding the possible intergenerational transmission of parents' smartphone use on adolescents' PSU (e.g., C. Kim & Kang, 2020; Lian,

You, Huang, & Yang, 2016), the role of parents' smartphone use should be considered. In addition, gender could be another confounding factor since some research found that girls might be more vulnerable to PSU (e. g., Lee & Lee, 2017). Therefore, along with demographics such as age at survey onset and education category, we also included parental smartphone use and adolescents' gender as covariates.

2. Methods

2.1. Procedure

The study procedures were carried out in accordance with the Declaration of Helsinki and were approved by the board of ethics of the Faculty of Social Sciences at Utrecht University (FETC16-076 Eijnden). Data for this study were collected annually between 2016 and 2018 (T1-T3) based on convenience sampling, as a part of the Digital Youth Project (Boer, Stevens, Finkenauer, & Van den Eijnden, 2020). In addition, the short version of smartphone addiction scale and smartphone use of parents started being measured from T2. A passive consent procedure was used: all students in the participating schools were given an information sheet about the study to bring home to their parents, and all students whose parents did not object to participation were included in the study. Participants filled out the survey anonymously in the classroom (with unique ID for the longitudinal tracing). Participation was voluntary and no incentives were given.

2.2. Participants

Regarding the longitudinal data, 2100 Dutch secondary school students participated in the survey of T1, 1750 participants completed the surveys for T1 and T2, and 919 participants completed all surveys for T1-T3. At T1, boys and girls were equally distributed (56.7% boys) and the mean age was 13.310 ($SD = 0.914$). Most of the students were born in the Netherlands (96.0%), and the distribution of students' education category is: 50.9% VMBO, 17.9% VMBO/HAVO, 7.8% HAVO, 19.3% HAVO/VWO, 4.0% VWO. VMBO refers to pre-vocational education, HAVO to intermediate education, VWO to pre-university education. VMBO/HAVO and HAVO/VWO reflect the combination of multiple education categories in the same class. Pre-university education was relatively underrepresented based on the statistics of Dutch adolescent population (Boer, Stevens, Finkenauer, de Looze, & van den Eijnden, 2021; Statistics Netherlands, 2019).

2.3. Measurements

The short version of *smartphone addiction scale* (SAS-SV) developed by Kwon, Kim, et al. (2013) was used to assess the extent to which the adolescents were "addicted" to their smartphones. It contains 10 items which were rated from 1 (completely disagree) to 5 (completely agree). We translated and adapted the original SAS-SV from English to Dutch with several rounds of double-checks, in which covariances among items 1–3 and items 4–7 were added based on the suggestions from previous studies (Kwon, Kim, et al., 2013; Kwon, Lee, et al., 2013; Luk et al., 2018). The results of CFA (confirmatory factor analysis) are as follows: CFI = .910, TLI = .884, RMSEA = .087, indicating an acceptable model fit. We adopted the SAS-SV in the measurements of T2 and T3, the Cronbach's α of the two waves showed good internal reliabilities (T2: .894; T3: .886).

Active social media messaging on smartphone was evaluated by asking participants about the frequency they send a message, photo or video via their smartphones per day. It was recorded from 1 (Less than once a day) to 7 (More than 80 times). The scoring was based on a small pilot study and the previous work investigating social media use intensity (Boer et al., 2021).

Passive social media messaging on smartphone was assessed by asking participants about the frequency they look on their smartphones to see if

a message, photo or video has arrived per day. It was recorded from 1 (Less than once a day) to 7 (More than 80 times). The scoring was also based on the same pilot study and the previous work as active social media messaging on smartphone (Boer et al., 2021).

Intensity of face-to-face meeting with friends was measured with a 4-item scale aimed at estimating the frequency of participants meeting with their friends in person across different situations (e.g., out of school, at home and so on) with a 6-point Likert scale ranging from 1 (never) to 6 (very often). The Cronbach's α of the three waves showed good internal reliabilities (T1: .849; T2: .863; T3: .854) across the three waves' data collection.

Perceived competence in close friendships is a Dutch scale to assess adolescents' abilities to develop and sustain their friendships (Harter, 1988; Treffers et al., 2002). The scale included 5 items with answers ranging from 1 (completely disagree) to 5 (completely agree). The Cronbach's α of the three waves showed to be relatively low, but acceptable (T1: .648; T2: .656; T3: .663). Although the coefficients of Cronbach's α were relatively low, we have found that all item-total correlations were over .350.

Perceived smartphone use of parents was estimated at T2 by asking adolescents to report the frequency their parents use smartphones or tablets under various conditions (e.g., dinner, conversations and so on) with four questions. Participants gauged their parents' smartphone use frequency from 1 (never) to 6 (very often). The Cronbach's showed satisfactory internal reliabilities (T2: .799; T3: .785) across the two waves' data collection.

Demographic information including age at survey onset, gender, and education category of each participant were also collected in our survey.

2.4. Statistical analysis

Cross-lagged panel analysis was applied to investigate the stability and relationships between the study variables over the course of the three measurement waves in order to identify how variables impact each other (Kearney, 2017). For each research question, four nested models (Model 0 to Model 3) were tested to compare which model provided the best fit to the data. For example, to explore whether active and passive social media messaging on smartphone showed a reciprocal relationship, Model 0, the baseline model, assumed significant auto-regressive relationships and within-time correlations for active and passive social media messaging but no lagged effects. Model 1 and Model 2 assumed directional lagged associations between active and passive social media messaging. Model 1 assumed that active social media messaging affected passive social media messaging, while Model 2 assumed that passive social media messaging impacted active social media messaging. Model 3 assumed reciprocal relationships, with both active and passive social media messaging having cross-lagged effects on each other. Chi-square difference tests were used to compare the models for each proposed research question. We expected that Model 3 (i.e., the reciprocal model) would show a better fit compared to the other models (i.e. Model 0-Model 2). In addition, measurement invariance (MI) analyses were conducted to confirm all constructs were measured in the same way at different time points prior to the cross-lagged analyses (Meredith, 1993). For the sensitivity analyses, the confounding factors (i.e., age at survey onset, gender, education category and smartphone use of parents at T2) were explored.

SPSS 26.0 (George & Mallery, 2019; Pallant, 2020) was used for descriptive analyses. We used Mplus 8.3 (Muthén & Muthén, 2017) to do the multi-group confirmatory factor analysis, cross-lagged panel analyses and exploratory analyses (e.g., mediation analyses).

3. Results

3.1. Measurement invariance (MI) and descriptive statistics

The results of measurement invariance analyses are shown in Table 1

of changed CFI (increase of ≥ 0.01) and RMSEA (decrease of ≥ 0.015), the unconstrained models did not fit better than the constrained models (Boer et al., 2020; van de Schoot, Lugtig, & Hox, 2012). Measurement invariances were therefore established over time, indicating that we could continue to test the longitudinal associations.

The descriptive and correlation analyses can be found in Table 2.

3.2. Model comparisons

3.2.1. Bidirectional relationships between active and passive social media messaging on smartphone among adolescents

According to the model fits shown in Table 3, Model 2 fitted the data significantly better than Model 0 ($\Delta\chi^2 = 195.849$, $p < .001$) and the chi-square difference between Model 2 and Model 3 was significant ($\Delta\chi^2 = 60.030$, $p < .001$), indicating that Model 3 significantly improved the model specification. Thus, Model 3 provided the best fit to the data, indicating positive cross-lagged associations between active and passive social media messaging on smartphone.

3.2.2. Bidirectional relationships between online (i.e., active and passive social media messaging on smartphone) and offline quantity of peer engagement (i.e., intensity of face-to-face meeting with friends) among adolescents

Based on the results from 3.2.1, M0-M3 were developed (i.e., the established cross-lagged effects were added). According to the model fits shown in Table 4, Model 1 fitted the data significantly better than Model 0 ($\Delta\chi^2 = 70.945$, $p < .001$) and the chi-square difference between Model 1 and Model 3 was significant ($\Delta\chi^2 = 42.704$, $p < .001$), indicating that Model 3 significantly improved the model specification. Thus, Model 3 provided the best fit to the data, indicating positive cross-lagged associations between online and offline quantity of peer engagement.

3.2.3. Bidirectional relationships between the quantity (i.e., online and offline) and quality of peer engagement among adolescents

Based on the results from 3.2.1 to 3.2.2, M0-M3 were developed (i.e., the established cross-lagged effects were added). According to the model fits shown in Table 5, Model 1 fitted the data significantly better than Model 0 ($\Delta\chi^2 = 97.235$, $p < .001$) and the chi-square difference between Model 1 and Model 3 was significant ($\Delta\chi^2 = 15.247$, $p < .05$), indicating that Model 3 significantly improved the model specification. Thus, Model 3 provided the best fit to the data, indicating that the quantity (i.e., online and offline) and quality of peer engagement have cross-lagged effects on each other.

3.2.4. Bidirectional relationships between the quantity (i.e., online and offline) and quality of peer engagement and problematic smartphone use

Based on the results from 3.2.1 to 3.2.3, M0-M3 were developed (i.e., the established cross-lagged effects were added). According to the model fits shown in Table 6, Model 2 fitted the data significantly better than Model 0 ($\Delta\chi^2 = 41.030$, $p < .001$) and the chi-square difference between Model 2 and Model 3 was significant ($\Delta\chi^2 = 23.133$, $p < .001$), indicating that Model 3 significantly improved the model specification. Thus, Model 3 provided the best fit to the data, indicating that the quantity (i.e., online and offline) and quality of peer engagement and PSU have cross-lagged effects on each other.

3.3. The final cross-lagged model including problematic smartphone use, active social media messaging on smartphone, passive social media messaging on smartphone, intensity of face-to-face meeting with friends and perceived competence in close friendship

The final cross-lagged model could be regarded as two parts: a. auto-regressive relationships and within-time correlations for problematic smartphone use, active social media messaging, passive social media messaging, intensity of face-to-face meeting with friends and perceived competence in close friendship; b. the cross-lagged associations between problematic smartphone use, active social media messaging, passive social media messaging, intensity of face-to-face meeting with friends and perceived competence in close friendship.

The auto-regressive relationships and within-time correlations for problematic smartphone use, active social media messaging, passive social media messaging, intensity of face-to-face meeting with friends and perceived competence in close friendship, the standardized coefficients of the auto-regressive relationships and within-time correlations are depicted in Figure 1.

The cross-lagged effects among problematic smartphone use, active social media messaging, passive social media messaging, intensity of face-to-face meeting with friends and perceived competence in close friendship, and the standardized coefficients of cross-lagged effects are illustrated in Figure 2.

The results indicated a bidirectional association between problematic smartphone use and active social media messaging: active social media messaging at T1 positively predicted problematic smartphone use at T2 and problematic smartphone use at T2 positively predicted active social media messaging at T3. The results also indicated a reciprocal cross-lagged association between problematic smartphone use and passive social media messaging: passive social media messaging at T1 and T2 positively predicted problematic smartphone use at T2 and T3 separately, and problematic smartphone use at T2 positively predicted passive social media messaging at T3. There were no associations between problematic smartphone use and intensity of face-to-face meeting with friends over time while the associations between problematic smartphone use and perceived competence in close friendship were bidirectional: perceived competence in close friendship at T1 negatively predicted problematic smartphone use at T2 and problematic smartphone use at T2 negatively predicted perceived competence in close friendship at T3.

The results also showed that the associations between active social media messaging and intensity of face-to-face meeting with friends were reciprocal: active social media messaging at T1 positively predicted intensity of face-to-face meeting with friends at T2 and intensity of face-to-face meeting with friends at T1 also positively predicted active social media messaging at T2, and their associations from T2 to T3 were the same. The associations between active social media messaging and perceived competence in close friendship were bidirectional: perceived competence in close friendship at T1 positively predicted active social media messaging at T2 and active social media messaging at T2 positively predicted perceived competence in close friendship at T3.

3.4. Additional exploratory analysis: the mediating effect of problematic smartphone use T2 in the relationship between perceived competence in close friendship T1 and T3

As problematic smartphone use at T2 was significantly related to perceived competence in close friendship at T1 and T3, we were interested in the possible mediating role of problematic smartphone use at T2 in the relationship between perceived competence in close friendship at T1 and T3. Thus, this mediation effect was estimated in the final model (Figure 3).

When both problematic smartphone use at T2 and perceived competence in close friendship at T1 were included in the model, the association of problematic smartphone use at T2 with perceived competence in close friendship at T3 remained significant. The bias-corrected bootstrap 95% indicated that the indirect effect through problematic smartphone use at T2 was significant ([0.002, 0.02]), showing that problematic smartphone use at T2 mediated the negative relationship between perceived competence in close friendship at T1 and T3.

3.5. Sensitivity analyses: sex, age, education category, perceived parental smartphone use

The possible confounding factors included gender, age at survey onset, education category and smartphone use of parents at T2 were investigated. Based on the results of sensitivity analyses, none of the factors significantly improved the model specification, thus, the cross-lagged model without any confounders was maintained.

4. Discussion

Though some studies have explored the relationships between adolescents' PSU and quantity and quality of peer engagement, longitudinal results are still limited. In the present study, we investigated the cross-lagged relationships between PSU and quantity and quality of peer engagement including online peer engagement (i.e., passive and active social media messaging on smartphone), offline peer engagement (i.e., intensity of face-to-face meeting with friends), and perceived competence in close friendships with a three-wave longitudinal survey. We found that the associations between PSU and adolescents' offline and online peer engagement and perceived competence in close friendships were bidirectional, and that the associations between offline and online peer engagement, and perceived competence in close friendships were also bidirectional.

Our first hypothesis was about the bidirectional positive associations between PSU and both active and passive social media messaging on smartphone. In line with our hypothesis, we found that higher intensity of active and passive social media messaging on smartphone were positively associated with adolescents' PSU. As for the directionality, the associations between passive social media messaging and PSU were reciprocally cross lagged while the associations between active social media messaging and PSU were not completely bidirectional (i.e. active social media messaging at T2 did not predict PSU at T3), indicating that passive social media messaging better predicted adolescents' PSU than active social media messaging. The results are consistent with the findings that passive social media messaging is more strongly related to negative outcomes like PSU in comparison to active social media messaging (Allegrante & Sigfusdottir, 2019; Ding, Zhang, Wei, Huang, & Zhou, 2017; Hu & Liu, 2020; J. L.; Wang, Gaskin, Rost, & Gentile, 2018).

Regarding the quantity of offline peer engagement, there were basically no significant associations between intensity of face-to-face meeting with friends and adolescents' PSU, except for the positive correlation between PSU at T2 and intensity of face-to-face meeting with friends at T2. This finding is to some extent in line with the results from a recent study, in which face-to-face contacts with friends were not related to adolescent's social media messaging problems (Boer et al., 2021). The possible reason could be the protective effect of intensity of face-to-face meeting with friends on PSU is kind of indirect and thus insignificant (Caplan, 2003; M. T. Wang & Hofkens, 2020).

Our second research hypothesis was on the bidirectional negative relationship between PSU and the quality of peer engagement. Consistent with our hypothesis, lower perceived competence in close friendships was positively associated with adolescents' higher PSU, which is consistent with previous studies (Kwak, Kim, & Yoon, 2018; Lee & Lee, 2017; Y. Wang et al., 2017). For example, adolescent's PSU related positively to relational maladjustment with peers in school (Kwak et al., 2018), and negatively associated with the quality of student-student relationship at school (Y. Wang et al., 2017). In contrast, PSU could also negatively influence adolescents' perceived competence in close friendships. This is supported by the found mediating role of PSU at T2 in the relationship between perceived competence in close friendships at T1 and T3, and consistent with studies showing that the intrusive effects of smartphone on communication in real life could do harm to adolescents' close relationships (Hales et al., 2018; Noë et al., 2019; Przybylski & Weinstein, 2013; Rotondi et al., 2017). The negative relationship between PSU and perceived competence in close friendship is similar to

the found downward spiral relationship between internet gaming disorder (IGD) and perceived social competence (Peeters et al., 2018; Van Den Eijnden, Koning, Doornwaard, Van Gurp, & Bogt, 2018). Adolescents with low perceived competence in close friendships seem more vulnerable to PSU since they might tend to use their smartphone more excessively to compensate for lack in social connection with their peers. In turn, excessive smartphone use could disturb interactions with peers and could thereby lead to even lower perceived competence in close friendships (Van Den Eijnden et al., 2018). This pattern also aligns with the poor-get-poorer hypothesis, although we have to note it would also be necessary to confirm whether adolescents have succeeded or not in enhancing their connections with peers via smartphone (Snodgrass et al., 2018). In addition, lower perceived social competence in the context of PSU could also reflect be a criterion for PSU as a possible behavioral addiction (Kardefelt-Winther et al., 2017; Van Den Eijnden et al., 2018).

We have also tested the bidirectional relationships between the quantity of online peer engagement (i.e., active and passive social media messaging on smartphone) and offline peer engagement (i.e., intensity of face-to-face meeting with friends) and the quality of peer engagement (i.e., perceived competence in close friendships) over time. In terms of active social media messaging, we found that there were positive and reciprocal cross-lagged correlations between active social media messaging on smartphone and intensity of face-to-face meeting with friends over time, which means that adolescents would meet with their friends in person more frequently when they are texting or sharing photo and videos actively, rather than just receiving the messages passively via social media. This intuitively makes sense, since adolescents could maintain contacts with their friends by actively interacting with others through social media, creating more possibilities to meet in person (Davies, 2014; Davis, 2012; Nesi et al., 2018). Meanwhile, meeting friends in real life would conversely promote active social media messaging, suggesting that adolescents tend to interact with the friends they already know and interact with in-person (Davies, 2014; Floros et al., 2015). Within-time correlations were found between perceived competence in close friendships at T1 and active social media messaging at T1 in current study. In addition, perceived competence in close friendships at T1 predicted active social media messaging at T2 and active social media messaging at T2 predicted perceived competence in close friendships at T3. These results are consistent with the transformation theory, suggesting that adolescents could have more opportunities to actively exert their abilities of developing and sustaining close friendships, and that frequent communications with peers via social media could further foster perceived competence in close friendships (Allegrante & Sigfusdottir, 2019; Nesi et al., 2018).

As for passive social media messaging on smartphone, only intensity of face-to-face meeting with friends predicted adolescents' passive social media messaging, not vice versa, meaning that adolescents tend to passively check the messages from the people they would meet in person while the passive checking has no effects on possibilities of meeting with friends. There were no associations between passive social media messaging and perceived competence in close friendships. The difference between active and passive social media messaging' associations with perceived competence in close friendships is compatible with the previous study (Allegrante & Sigfusdottir, 2019; Escobar-Viera et al., 2018), indicating that active social media messaging on smartphone is more closely related to the quality of peer engagement.

4.1. Limitations and future directions

A strength of the current study is the longitudinal investigation of the mechanisms of adolescents' PSU in terms of both quantity and quality of peer engagement. However, there are also several limitations that need to be addressed in future studies.

Firstly, participants were followed over the three waves and PSU was measured twice. Longer studies with more waves may identify more

comprehensive dynamic models on relationships between the quantity and quality of peer engagement and PSU. Especially, the mediating effect of PSU in our study implicates that the possible developmental cascade effects between PSU and perceived competence in close friendships should be further investigated with longer intervals (Blandon, Calkins, Grimm, Keane, & O'Brien, 2010; Bornstein et al., 2010).

Secondly, we have used four variables to gauge the quantity and quality of peer engagement among adolescents, while other indicators like friends selection, numbers of friends, and peer influences online and offline also need to be considered when testing the associations between PSU and adolescents' peer engagement (Davies, 2014; Huang et al., 2014; Smahel, Brown, & Blinka, 2012). Moreover, though we have found that active and passive social media messaging function differently, future work is needed to determine the underlying mechanism and more validated measures for active and passive social media use, not just social media messaging should be applied (Gerson, Plagnol, & Corr, 2017; Trifiro & Gerson, 2019). Besides, the scale of perceived competence in close friendships has shown relatively low internal consistencies in present study. Therefore, other scales assessing social competence with better internal consistency (e.g., Harter, 2012) could be used in further studies. Apart from that, future work could even detect adolescents' friendship via the co-locations of their smartphones (Malik, Doryab, Merrill, Pfeffer, & Dey, 2020).

Thirdly, the debate surrounding PSU, including the similarities with behavioral addictions and the role of the activities on the smartphone, rather than the smartphone itself, needs to be addressed in future research (Elhai & Contractor, 2018; Horvath et al., 2020; Körmendi et al., 2016; Panova & Carbonell, 2018). As a first step, we mainly focused on the role of peer engagement in the development of PSU, in which we used social media messaging as an indicator of online peer engagement. It has been suggested that the activities on the phone, like general social media use (Noë et al., 2019; Rozgonjuk, Kattago, & Täht, 2018) and gaming (e.g., Liu, Lin, Pan, & Lin, 2016) drive PSU. This means that to understand PSU, it is important to focus on the specific activities, rather than the smartphone itself (e.g., Panova & Carbonell, 2018). In addition, objective measures on adolescents' and their parents' smartphone and social media use should be applied (e.g., Ryding & Kuss, 2020) since the self-reported measures were found to be only moderately correlated to the objective logs (see a review, Parry et al., 2021). Person-centered qualitative studies should be further applied to answer the question whether PSU is really a behavioral addiction without pathologizing normal smartphone use (Kardefelt-Winther et al., 2017).

The present study makes several notable contributions. At first, we found that passive social media messaging on smartphone and perceived competence in close friendship are two salient factors that could influence adolescents' PSU, which should be included when designing the protocols for smartphone use interventions. As for the promotion of adolescents' social competence (Stichter, Herzog, Owens, & Malugen, 2016), the importance of active interactions online for meetings with friends in-person, as well as the detrimental influences of smartphone use on the quality of relationships should be emphasized. Besides, the different effects of active and passive social mediamessaging found here should also be noted in both practical and theoretical research in the area. For instance, a balance of active and passive social media messaging could be a viable point to reach the goal of "digital well-being" (i.e. the dynamic equilibrium between the pains and gains one person could get from mobile connectivity like smartphone; Vanden Abeele, 2020).

4.2. Conclusion

To conclude, the current study provides longitudinal evidence, showing that adolescents who perceive a low competence in close friendships and frequently check messages from their peers on smartphone would have a higher risk to develop problematic smartphone use over time. Our findings also suggest that the balance between active and passive social media messaging should be attained to benefit adolescents' well-being.

Credit author statement

Shuang Su: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing - Original Draft, Writing - Review & Editing, Visualization; Helle Larsen: Conceptualization, Methodology, Validation, Writing - Review & Editing, Supervision; Janna Cousijn: Conceptualization, Methodology, Validation, Writing - Review & Editing, Supervision; Reinout W. Wiers: Conceptualization, Methodology, Validation, Writing - Review & Editing, Supervision; Regina J.J. M. Van Den Eijnden: Conceptualization, Methodology, Investigation, Resources, Data Curation, Writing- Reviewing and Editing, Supervision, Project administration, Funding acquisition.

Acknowledgements

Appendix A

Figures.
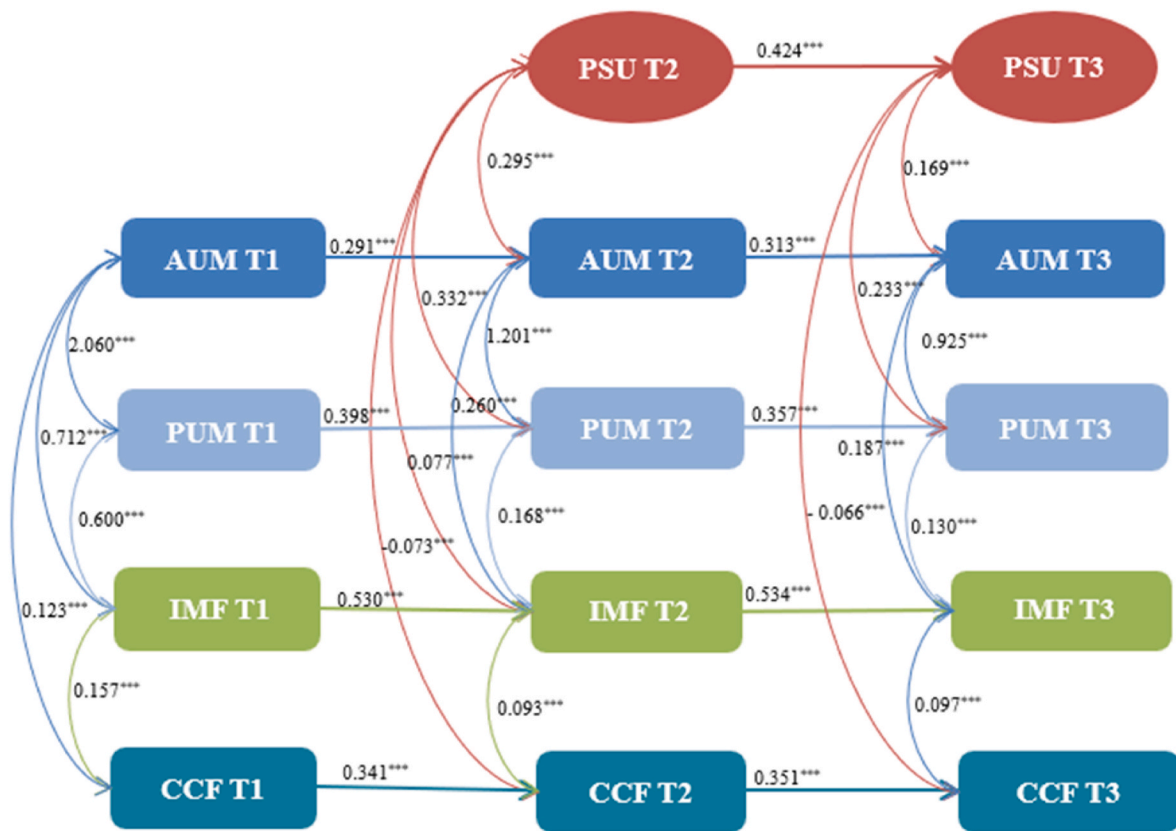
Fig. 1. The standardized coefficients of the auto-regressive and within-time effects in the final model. *Note.* PSU = problematic smartphone use, AUM = active social media messaging on smartphone, PUM = passive social media messaging on smartphone, CCF = perceived competence in close friendships, IMF = intensity of face-to-face meeting with friends; T1 = Time 1, T2 = Time 2, T3 = Time 3. Only the significant paths are showed in the figure, *p < .05, **p < .01, ***p < .001.
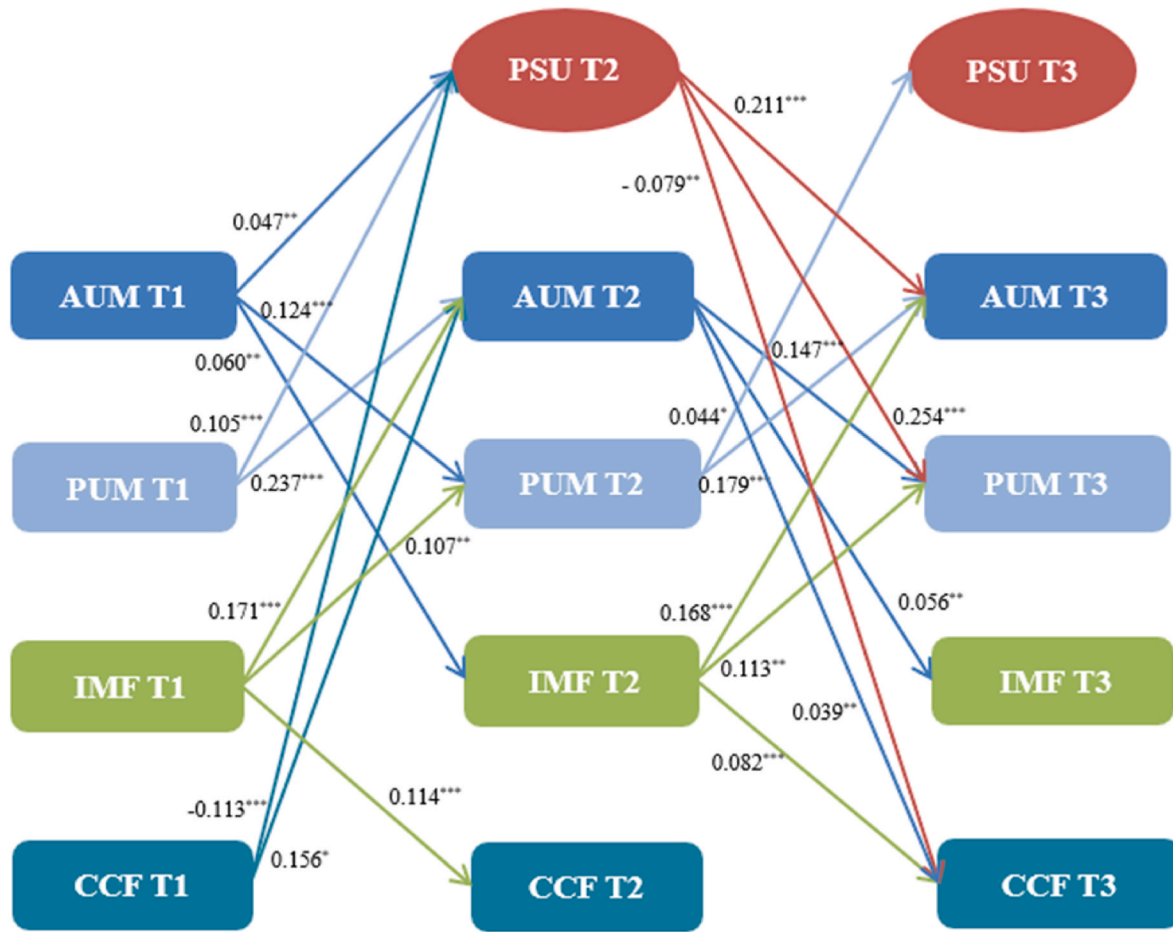
Fig. 2. The standardized coefficients of cross-lagged effects in the final model. *Note.* PSU = problematic smartphone use, AUM = active social media messaging on smartphone, PUM = passive social media messaging on smartphone, CCF = perceived competence in close friendships, IMF = intensity of face-to-face meeting with friends; T1 = Time 1, T2 = Time 2, T3 = Time 3. Only the significant paths are showed in the figure, $*p < .05$, $**p < .01$, $***p < .001$.
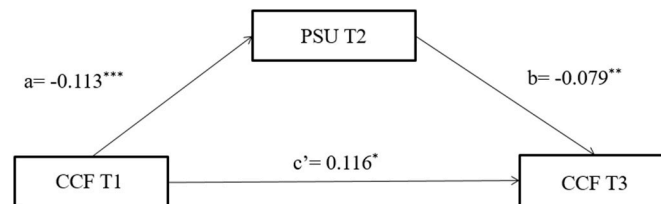

Fig. 3. The mediation effect of problematic smartphone use at T2 on the relationship between perceived competence in close friendships at T1 and T3. *Note.* a, b and c' are expressed as the standardized regression coefficients. CCF T1 = perceived competence in close friendships at Time 1; CCF T3 = perceived competence in close friendships at Time 3; PSU T2 = problematic smartphone use at Time 2; $*p < .05$, $**p < .01$, $***p < .001$.

Appendix B

Table 1
Measurement invariance analysis: Multi-group CFA.

	Overall model fit constrained model			Changes in model fit	
	CFI	TLI	RMSEA	ΔCFI	ΔRMSEA
PSU	.911	.893	.052	.004	.002
IMF	.987	.983	.027	.009	-.010
CCF	.935	.923	.030	.003	.002

Note. PSU = problematic smartphone use, CCF = perceived competence in close friendships, IMF = intensity of face-to-face meeting with friends; CFA = confirmatory factor analysis, CFI = comparative fit index, TLI = Tucker–Lewis index, RMSEA = root mean square error of approximation; changes in model fit were the results from the comparisons between the unconstrained model (i.e., the factor loadings and item intercepts were free over time) and constrained model (i.e., the factor loadings and item intercepts were the same over time).

Table 2

Means, standard deviations and correlations of problematic smartphone use, active and passive social media messaging on smartphone, intensity of face-to-face meeting with friends, and perceived competence in close friendships over the three-wave measurements.

Variables	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.PSU T2	2.148	0.799	1													
2. PSU T3	2.131	0.759	.499***	1												
3.AUM T1	4.270	1.815	.220***	.161***	1											
4.AUM T2	4.280	1.763	.337***	.260***	.482***	1										
5.AUM T3	4.020	1.670	.311***	.331***	.440***	.522***	1									
6.PUM T1	4.310	1.628	.255***	.174***	.692***	.450***	.434***	1								
7.PUM T2	4.510	1.586	.407***	.303***	.444***	.711***	.481***	.516***	1							
8.PUM T3	4.390	1.545	.358***	.423***	.415***	.501***	.673***	.536***	.559***	1						
9. IMF T1	3.492	1.085	.061*	.039	.359***	.280***	.254***	.339***	.261***	.245***	1					
10. IMF T2	3.393	1.118	.143***	.113***	.288***	.344***	.283***	.249***	.284***	.255***	.545***	1				
11. IMF T3	3.376	1.065	.084**	.111***	.273***	.314***	.323***	.271***	.283***	.289***	.500***	.585***	1			
12. CCF T1	4.325	0.702	-.087**	-.148***	.092***	.099***	.080*	.039	.052	.031	.198***	.125***	.162***	1		
13. CCF T2	4.317	0.702	-.150***	-.096***	.102***	.113***	.065*	.050	.074**	.058*	.217***	.273***	.184***	.355***	1	
14. CCF T3	4.325	0.695	-.117***	-.166***	.103**	.131***	.088***	.076*	.084**	.034	.162***	.243***	.286***	.309***	.414***	1

Note. PSU = problematic smartphone use, AUM = active social media messaging on smartphone, PUM = passive social media messaging on smartphone, IMF = intensity of face-to-face meeting with friends, CCF = perceived competence in close friendships; T1 = Time 1, T2 = Time 2, T3 = Time 3; *p < .05, **p < .01, ***p < .001.

Table 3

Fit statistics for the nested models on the cross-lagged relationships between active and passive social media messaging on smartphone.

Model	AIC	χ^2	df	CFI	TLI	RMSEA
Model 0	45,801.178	315.242	8	.907	.837	.101
Model 1	45,606.080	141.836	6	.959	.904	.078
Model 2	45,576.640	119.393	6	.966	.920	.071
Model 3	45,512.440	59.363	4	.983	.941	.061

Note. Model 0: auto-regressive relationships and within-time correlations for active and passive social media messaging on smartphone but no lagged effects; Model 1: active social media messaging on smartphone has a directional lagged effect on passive social media messaging on smartphone; Model 2: passive social media messaging on smartphone has a directional lagged effect on active social media messaging on smartphone; Model 3: active and passive social media messaging on smartphone have cross-lagged effects on each other.

Table 4

Fit statistics for the nested models on the cross-lagged relationships between offline and online peer engagement.

Model	AIC	χ^2	df	CFI	TLI	RMSEA
Model 0	63,743.273	201.686	17	. 959	.921	.053
Model 1	63,667.006	130.741	13	.974	.934	.049
Model 2	63,686.319	142.151	13	.971	.927	.051
Model 3	63,629.189	88.037	9	.982	.936	.048

Note. Model 0: auto-regressive relationships and within-time correlations for online and offline peer engagement but no lagged effects; Model 1: online peer engagement has a directional lagged effect on offline peer engagement; Model 2: offline peer engagement has a directional lagged effect on online peer engagement; Model 3: online and offline peer engagement have cross-lagged effects on each other.

Table 5

Fit statistics for the nested models on the cross-lagged relationships between the quantity and quality of peer engagement.

Model	AIC	χ^2	df	CFI	TLI	RMSEA
Model 0	76,947.375	220.387	28	.965	.925	.043
Model 1	76,850.409	123.152	22	.982	.950	.035
Model 2	76,938.854	197.402	22	.968	.913	.046
Model 3	76,849.667	107.905	16	.983	.937	.039

Note. Model 0: auto-regressive relationships and within-time correlations for the quantity and quality of peer engagement but no lagged effects; Model 1: the quantity of peer engagement has a directional lagged effect on the quality of peer engagement; Model 2: the quality of peer engagement has a directional lagged effect on the quantity of peer engagement; Model 3: the quantity and quality of peer engagement have cross-lagged effects on each other.

Table 6

Fit statistics for the nested models on the cross-lagged relationships between the quantity and quality of peer engagement and PSU.

Model	AIC	χ^2	df	CFI	TLI	RMSEA
Model 0	86,001.174	171.663	28	.977	.934	.037
Model 1	85,968.403	137.270	24	.982	.938	.035
Model 2	85,958.688	130.633	24	.983	.943	.034
Model 3	85,939.364	107.500	20	.986	.942	.034

Note. Model 0: auto-regressive relationships and within-time correlations for the quantity and quality of peer engagement and PSU; Model 1: the quantity and quality of peer engagement have a directional lagged effect on PSU; Model 2: PSU has a directional lagged effect on the quantity and quality of peer engagement; Model 3: the quantity and quality of peer engagement and PSU have cross-lagged effects on each other.

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