Journal of Behavioral Addictions 6(1), pp. 30–41 (2017)
DOI: 10.1556/2006.6.2017.019

The relationship between second-to-fourth digit (2D:4D) ratios and problematic and pathological Internet use among Turkish university students

FATIH CANAN[1]*, SERVET KARACA[2], MELIKE DÜZGÜN[3], AYŞE MERVE ERDEM[3], ESRANUR KARAÇAYLI[3], NUR BEGÜM TOPAN[3], SANG-KYU LEE[4], ZU WEI ZHAI[1], MURAT KULOĞLU[2] and MARC N. POTENZA[1,5,6,7]

[1]Department of Psychiatry, Yale School of Medicine, New Haven, CT, USA
[2]Department of Psychiatry, Akdeniz University School of Medicine, Antalya, Turkey
[3]Akdeniz University School of Medicine, Antalya, Turkey
[4]Department of Psychiatry, Hallym University Medical Center, Chuncheon Sacred Heart Hospital, Chuncheon, South Korea
[5]The National Center on Addiction and Substance Abuse, Yale School of Medicine, New Haven, CT, USA
[6]The Connecticut Mental Health Center, New Haven, CT, USA
[7]Department of Neuroscience and Child Study Center, Yale School of Medicine, New Haven, CT, USA

(Received: October 5, 2016; revised manuscript received: February 1, 2017; accepted: March 12, 2017)

Background and aims: The ratio of the second and fourth fingers (2D:4D ratio) is a sexually dimorphic trait, with men tending to have lower values than women. This ratio has been related to prenatal testosterone concentrations and addictive behaviors including problematic video-gaming. We aimed to investigate the possible association between 2D:4D ratios and Internet addiction and whether such a relationship would be independent of impulsivity. *Methods:* A total of 652 university students (369 women, 283 men), aged 17–27 years, were enrolled in the study. Problematic and pathological Internet use (PPIU) was assessed using the Internet Addiction Test (IAT). The participants also completed the Barratt Impulsiveness Scale (version 11; BIS-11) and had their 2D:4D ratios measured. *Results:* 2D:4D ratios were not significantly different in women with PPIU and in those with adaptive Internet use (AIU). Men with PPIU exhibited lower 2D:4D ratios on both hands when compared with those with AIU. Correlation analysis revealed that 2D:4D ratios on both hands were negatively correlated with IAT scores among men, but not among women. The multiple linear regression analysis revealed that age, duration of weekly Internet use, impulsiveness, and 2D:4D ratios on the right hand were independently associated with IAT scores among men, and impulsivity did not mediate the relationship between 2D:4D ratios and PPIU. *Conclusions:* For men, 2D:4D ratios on the right hand were inversely correlated with Internet addiction severity even after controlling for individual differences in impulsivity. These findings suggest that high prenatal testosterone levels may contribute to the occurrence of PPIU among men.

Keywords: digit ratio, impulsivity, Internet addiction, 2D:4D, testosterone

INTRODUCTION

The ratio of second-to-fourth digit length (2D:4D ratio) is determined during the fetal period and becomes stable across the lifespan starting at 2 years of age (Manning, Trivers, Thornhill, & Singh, 2000). Prenatal androgen exposure and responsiveness have been cited as predictors of 2D:4D ratios (Lutchmaya, Baron-Cohen, Raggatt, Knickmeyer, & Manning, 2004; Manning, Bundred, Newton, & Flanagan, 2003). Differences in 2D:4D ratios between men and women are consistent with a relationship between prenatal testosterone concentrations and 2D:4D ratios (Fink, Neave, & Manning, 2003; Malas, Dogan, Evcil, & Desdicioglu, 2006; McFadden & Shubel, 2002). Also consistently, lower 2D:4D ratios have been reported in women with congenital adrenal hyperplasia, a condition involving exposure to elevated levels of testosterone *in utero* (Okten, Kalyoncu, & Yariş, 2002). As a consequence of fetal testosterone exposure, the 2D:4D ratio has a sexually dimorphic feature, with men tending to have smaller values than women (Manning et al., 2000). Twin studies, however, have shown that genetic factors are also contributed to this ratio (Gobrogge, Breedlove, & Klump, 2008; Paul, Kato, Cherkas, Andrew, & Spector, 2006).

In utero testosterone exposure not only decreases the 2D:4D ratio but also "defeminizes" the brain (Williams et al., 2000). Accordingly, typical masculine traits, such as aggression (Bailey & Hurd, 2005; Gorka, Norman, Radtke, Carré, & Hariri, 2015), reproductive success, sociosexuality, dominance (Manning & Fink, 2008), and competitiveness (Manning & Taylor, 2001), have been shown to be inversely correlated with 2D:4D ratios. Many psychiatric disorders are associated with variations in 2D:4D ratios as well.

* Corresponding author: Fatih Canan; Department of Psychiatry, Yale School of Medicine, New Haven, CT 06510, USA; Phone: +1 203 8922744; Fax: +1 203 9747366; E-mail: fatihcanan@gmail.com

While patients with attention-deficit/hyperactivity disorder (ADHD) (Stevenson et al., 2007) and autism (Manning, Baron-Cohen, Wheelwright, & Sanders, 2001) have exhibited smaller ratios, those with schizophrenia (Collinson et al., 2010), depression (Martin, Manning, & Dowrick, 1999), and eating disorders (Quinton, Smith, & Joiner, 2011; Smith, Hawkeswood, & Joiner, 2010) had higher values when compared with non-affected individuals.

In the past 5 years, multiple studies have demonstrated a relationship between alcohol or nicotine dependence and 2D:4D ratios (Borkowska & Pawlowski, 2013; Han, Bae, Lee, Won, & Kim, 2016; Kornhuber et al., 2011; Manning & Fink, 2011). Most have shown low 2D:4D ratios in alcohol dependence (Han et al., 2016; Kornhuber et al., 2011; Manning & Fink, 2011) and high 2D:4D ratios in nicotine dependence (Borkowska & Pawlowski, 2013; Kornhuber et al., 2011). These findings suggest a complex relationship between prenatal androgen exposure and addictive behaviors. Moreover, men with problematic video-gaming (a non-substance-related addictive behavior) exhibited lower 2D:4D ratios when compared with those with non-problematic video-gaming (Kornhuber et al., 2013). Therefore, the amount of fetal testosterone exposure may influence the likelihood of engaging in addictive behaviors, whether substance-related or not.

Impulsivity has been proposed as a vulnerability marker for addictive behaviors (Verdejo-García, Lawrence, & Clark, 2008). Individuals with substance use disorders often exhibit high levels of impulsivity (von Diemen, Bassani, Fuchs, Szobot, & Pechansky, 2008). Impulsivity has also been associated with 2D:4D ratios (Hanoch, Gummerum, & Rolison, 2012), which may point to a link between addictive behaviors, impulsivity, and prenatal androgen exposure.

Previous work has not examined the relationship between 2D:4D ratios and problematic and pathological Internet use (PPIU). Based on findings in men with problematic video-gaming, we hypothesized that we would observe low 2D:4D ratios in association with PPIU, particularly among men. We also hypothesized that this relationship would be related to impulsivity.

MATERIALS AND METHODS

Participants

We examined a convenience sample of 694 undergraduate students recruited from the main campus of Akdeniz University, Antalya, located in southern Turkey. This study is a part of a broader research effort aimed at the examination of addictive disorders and their relationship to various factors among undergraduate students. Participants were recruited through classes and a student volunteer subject pool. Data collection took place from January 2016 to May 2016. Individuals were not offered any compensation for their participation. After excluding students with incomplete data, the final analyzed sample consisted of 652 students.

Measures

Barratt Impulsiveness Scale, version 11 (BIS-11). The BIS-11 (Patton, Stanford, & Barratt, 1995) is a 30-item self-administered questionnaire that is widely used to evaluate the personality/behavioral construct of impulsiveness. It consists of three subscales: "attentional impulsiveness" (eight questions reflecting a reduced tendency to maintain attention toward a stimulus), "motor impulsiveness" (11 questions measuring rapid action-taking and acting without forethought), and "non-planning impulsiveness" (11 questions expressing a lack of planning and an emphasis on the present). The BIS-11 items use a 4-point Likert scale and item values range from 1 = *rarely/never* to 4 = *almost always*. Some items are reverse-scored such to make higher scores reflective of greater impulsivity. The Turkish version of the BIS-11 was found to be reliable among healthy students and patients with psychiatric disorders (Cronbach's α coefficient: .78 and .81, respectively) (Gulec et al., 2008).

Internet Addiction Test (IAT). We used the IAT (Young, 1998) to evaluate PPIU. The IAT is one of the most widely used instruments for the assessment of maladaptive Internet use. It does not identify the specific problematic Internet applications (e.g., online gaming, using the Internet for sociability, or pornography viewing). The IAT is self-administered and uses a Likert scale with response categories ordered from "0 = Does not apply" to "5 = Always." It includes 20 items, and the total score can range from 0 to 100. Young (2017) suggests that scores of 49 or lower indicate that the individual has adaptive Internet use (AIU), 50 or higher indicate that the individual has problematic Internet use, and 80 or higher indicate that the individual has pathological Internet use. These thresholds were used in several previous studies (e.g., Boysan et al., 2017; Ngai, 2012). The internal consistency of the Turkish version of the IAT was found to be high (Cronbach's α coefficient = .93) in a Turkish undergraduate sample (Boysan et al., 2017).

Measurement of 2D:4D ratios. The lengths of the second digit (the "index" finger) and fourth digit (the "ring" finger) were measured using a digital Vernier caliper (accurate to 0.01 mm). Participants were instructed to place their hands on the table with their palms facing up and to extend their fingers as much as possible. The lengths of the digit were measured from the most proximal crease to the palm of the hand to the tip of the finger as described by Verster and de Haan (2011). For each subject, two consecutive measurements were performed by two different observers. Each measurement was averaged to obtain a final value. The 2D:4D ratio was calculated by dividing the length of the index finger (second digit) by the length of the ring finger (fourth digit). The intraclass correlation coefficient (ICC) was used to assess the repeatability of 2D:4D ratios (average-score ICCs with absolute agreement definition; Voracek, Manning, & Dressler, 2007). The reliability of the two raters was high for the right hand (2D: ICC = 0.994; 4D: ICC = 0.995), the left hand (2D: ICC = 0.994; 4D: ICC = 0.992) as well as 2D:4D ratios on the right hand (ICC = 0.984) and 2D:4D ratios on the left hand (IC = 0.981).

Statistical analysis

We used IBM SPSS Statistics software version 20.0 (Armonk, NY, USA) to perform statistical analyses. Cohen's *d* statistics were calculated for two-group comparisons of means (Cohen, 1998). Student's *t*-tests were utilized to assess between-group differences with respect to

continuous variables. One-way analyses of variance (ANOVAs) were used to compare quantitative data among more than two groups (e.g., groups arranged in accordance with their most frequent Internet activities). To demonstrate the group differences, pairwise group comparisons were calculated using the Scheffé test. The χ^2 test was used to compare proportions between the groups. The correlation of IAT scores with participants' ages, impulsivity scores, 2D:4D ratios, and Internet use-related variables was analyzed using Pearson's correlation tests. The multiple linear regression analyses were used to investigate the relationships between the dependent variable (IAT score) and the multiple independent variables (e.g., age and duration of weekly Internet use).

Moderated mediation analysis on whether the indirect effect of 2D:4D ratios (independent variable) on PPIU (dependent variable) operated through BIS-11 scores (mediator) and was moderated by gender (moderator) in a single model was conducted in the widely used PROCESS for SPSS, which implements bootstrapping confidence intervals (CIs) to infer indirect effects (Hayes, 2013). Gender was included as a moderator in the relationships between 2D:4D ratios, PPIU, and BIS-11 scores. Analyses were repeated for both left- and right-hand 2D:4D ratios as the independent variables. Significant indirect effects of 2D:4D ratios on PPIU through BIS-11 scores for each gender were identified when the CIs did not include zero. Significant moderated mediation, corresponding to a between-gender difference in the indirect effect of 2D:4D ratios on PPIU through BIS-11, was identified when the index of moderated mediation CI did not include zero (Hayes, 2015).

Ethics

All participants were recruited with written informed consent and approval by the Committee for the Protection of Human Subjects of the Akdeniz University School of Medicine Institutional Review Board. This study conformed to the ethical guidelines of the 2013 Declaration of Helsinki.

RESULTS

The sample consisted of 369 women (56.6%) and 283 men (43.4%). The average age of participants was 20.8 ± 2.1 years (range: 17–27 years). The prevalence estimates of PPIU in the total sample were 12.9% and 2.8%, respectively. Given the relatively small number of participants with pathological Internet use ($n = 18$), the students with pathological Internet use and those with problematic Internet use were combined to form one group (with PPIU) for the analyses reported below. The average time spent online per week was 23.7 ± 14.6 hr. The Internet had been most frequently reported to be used for the following activities: online social networks (e.g., Facebook, Twitter, and Instagram) (48.3%); online streaming video (e.g., YouTube) (31.6%); Internet gaming (8.4%); online gambling (0.2%); online pornography (0.2%); and other activities (e.g., academic activities, e-mail checking, and reading the news) (11.3%).

As noted in Table 1, 13.6% of women and 18.4% of men were found to have PPIU ($p = .058$). Men scored higher on the IAT, as compared with women ($p = .004$). Women were more likely to use the Internet for social networking and streaming videos than were men. Compared with women, a higher proportion of men reported Internet gaming as their most frequent Internet activity ($p < .001$). Only two men reported online gambling and online pornography as their most frequent Internet activity. Thus, the following analyses conducted on the most frequently performed Internet activities did not include these two students. 2D:4D

Table 1. Comparison of students with respect to gender

		Women ($n = 369$)		Men ($n = 283$)		*T*-score or χ^2 value	Effect size (*d*)	*p* values
		Mean	*SD*	Mean	*SD*			
Age (years)[a]		20.5	2.0	21.2	2.2	4.042	0.31	<.001
Duration of weekly Internet use (hr/week)[a]		23.7	14.7	23.8	14.7	0.142	0.01	.887
IAT score[a]		30.0	16.8	34.1	18.4	2.917	0.12	.004
Attentional impulsiveness (BIS-11) score[a]		16.6	5.1	17.0	4.9	0.977	0.07	.329
Motor impulsiveness (BIS-11) score[a]		18.8	5.9	19.5	5.4	1.492	0.11	.136
Non-planning impulsiveness (BIS-11) score[a]		22.5	5.6	22.7	5.4	0.455	0.03	.649
Total impulsiveness (BIS-11) score[a]		58.1	13.0	59.3	11.8	1.264	0.10	.207
Right-hand 2D:4D ratio[a]		1.009	0.038	0.991	0.034	−6.302	0.50	<.001
Left-hand 2D:4D ratio[a]		0.997	0.037	0.990	0.035	−2.275	0.19	.023
PPIU status[b]	No	319 (86.4%)		231 (81.6%)		2.825		.058
	Yes	50 (13.6%)		52 (18.4%)				
Most frequent Internet activities[b]	Social networking	193 (52.3%)		122 (43.1%)		41.047		<.001
	Streaming videos	127 (34.4%)		79 (27.9%)				
	Gaming	10 (2.7%)		45 (15.9%)				
	Gambling	0		1 (0.4%)				
	Pornography viewing	0		1 (0.4%)				
	Other	39 (10.6%)		35 (12.4%)				

Note. BIS-11: Barratt Impulsivity Scale, version 11; IAT: Internet Addiction Test; PPIU: problematic and pathological Internet use.
[a]Student's *t*-test. [b]χ^2 test.

measurements for right and left hands were significantly higher in women than in men ($p < .001$ and $p < .023$, respectively).

Students with PPIU were younger ($p = .045$), used the Internet longer ($p < .001$), and scored higher on attentional impulsiveness ($p < .001$), motor impulsiveness ($p < .001$), and total impulsiveness ($p < .001$) than those with AIU (Table 2). Participants with PPIU were more likely to report gaming as their most frequent Internet activity and tended to be less likely to report using the Internet for other activities (e.g., academic purposes). The right-hand 2D:4D ratios of students with PPIU were significantly smaller than those of the students with AIU ($p = .008$). There were, however, no significant mean group differences in the left-hand 2D:4D measurements between students with PPIU and those with AIU, although the difference approached significance ($p = .068$).

As shown in Table 3, the duration of weekly Internet use and IAT and BIS-11 scores and right-hand 2D:4D ratios differed with respect to the most frequently reported Internet

Table 2. Comparison of students with and without PPIU

		AIU ($n = 550$)		PPIU ($n = 102$)		T-score or χ^2 value	Effect size (d)	p values
		Mean	*SD*	Mean	*SD*			
Age (years)[a]		20.9	2.1	20.4	2.0	2.012	0.16	.045
Duration of weekly Internet use (hr/week)[a]		21.7	13.3	34.7	16.1	−8.710	0.69	<.001
Attentional impulsiveness (BIS-11) score[a]		16.3	4.9	19.5	4.6	−6.119	0.48	<.001
Motor impulsiveness (BIS-11) score[a]		18.5	5.3	22.7	6.7	−7.039	0.56	<.001
Non-planning impulsiveness (BIS-11) score[a]		22.5	5.5	23.5	5.8	−1.712	0.14	.087
Total impulsiveness (BIS-11) score[a]		57.3	12.0	65.7	12.7	−6.455	0.51	<.001
Right-hand 2D:4D ratio[a]		1.003	0.036	0.993	0.041	2.660	0.21	.008
Left-hand 2D:4D ratio[a]		0.995	0.366	0.998	0.366	1.831	0.14	.068
Most frequent Internet activities ($n = 650$)[b]	Social networking	269 (49.1%)		46 (45.1%)		73.807		<.001
	Streaming videos	183 (33.4%)		23 (22.5%)				
	Gaming	25 (4.6%)		30 (29.4%)				
	Other	71 (13%)		3 (2.9%)				

Note. AIU: adaptive Internet use; BIS-11: Barratt Impulsivity Scale, version 11; IAT: Internet Addiction Test; PPIU: problematic and pathological Internet use.
[a]Student's t-test. [b]χ^2 test.

Table 3. Comparison of age, Internet-related outcomes, impulsiveness subscales, and digit ratios with respect to the most frequent Internet activities. One-way ANOVA with post-hoc Scheffé test

	Social networking ($n = 315$)		Streaming videos ($n = 206$)		Gaming ($n = 55$)		Other ($n = 74$)			
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	F-score	p values
Age (years)	20.8	2.1	20.8	2.2	20.8	1.9	20.8	2.1	0.312	.941
Duration of weekly Internet use (hr/week)	24.2	15	23	13.1	34.2	15.6	16.4	12.4	16.833	<.001[a]
IAT score	33.2	17.3	30.4	15.2	47	19.5	18.3	13.2	33.525	<.001[a]
Attentional impulsiveness (BIS-11) score	17	4.7	17.1	5.2	16.7	4.8	15.2	5.4	3.057	.028[b]
Motor impulsiveness (BIS-11) score	19.3	5.7	19.5	5.9	19.5	6.1	17.2	4.8	3.175	.024[b]
Non-planning impulsiveness (BIS-11) score	23.3	5.8	22.5	5.6	22	5	21.5	5.7	3.008	.056
Total impulsiveness (BIS-11) score	59.6	12.1	58.7	12.7	58.1	12.5	53.9	12.7	4.222	.006[c]
Right-hand 2D:4D ratio	1.004	0.037	1.004	0.036	0.987	0.045	0.996	0.034	4.204	.006[d]
Left-hand 2D:4D ratio	0.994	0.037	0.997	0.037	0.983	0.033	0.992	0.035	2.954	.062

Note. BIS-11: Barratt Impulsivity Scale, version 11; IAT: Internet Addiction Test.
Pairwise comparisons: [a]Social networking > others ($p < .01$); streaming videos > others ($p < .01$); gaming > social networking, streaming videos, and others ($p < .001$). [b]Social networking > others ($p < .05$); streaming videos > others ($p < .05$). [c]Social networking > others ($p < .01$); streaming videos > others ($p < .05$). [d]Gaming < social networking and streaming videos ($p < .05$).

activities. Students who used the Internet mostly for gaming exhibited smaller right-hand 2D:4D measurements than did those who used the Internet mostly for social networking and streaming videos ($p = .024$; $p = .026$, respectively). For women, however, a one-way ANOVA indicated that right-hand or left-hand 2D:4D measurements did not differ according to the most frequently reported Internet activities ($F = 3.707$, $p = .055$; $F = 0.307$, $p = .821$, respectively). For men, right-hand 2D:4D ratios, but not left-hand 2D:4D ratios, differed significantly with respect to the most frequently reported Internet activities ($F = 5.214$, $p = .002$; $F = 2.861$, $p = .053$, respectively). A post-hoc Scheffé test indicated that men who reported using the Internet mostly for gaming had significantly lower 2D:4D ratios on the right hand than those who stated to use the Internet mostly for social networking ($p = .005$) and streaming videos ($p = .006$).

Because of the significant differences found in 2D:4D ratios between men and women, we reanalyzed the findings for both sexes separately. Table 4 demonstrates the comparison of women with PPIU and AIU and that of men with PPIU and AIU. All three subscales and total scores of BIS-11 were significantly higher in women with PPIU than in those with AIU. No differences in 2D:4D ratios were found with respect to having PPIU. Women with PPIU were more likely to report using the Internet mostly for social networking and online gaming than those with AIU ($p = .005$).

Non-planning impulsiveness scores were comparable between men with PPIU and those with AIU ($p = .975$) (Table 4). Men with PPIU had significantly smaller 2D:4D ratios on both the right and the left hands when compared with those with AIU ($p < .001$ and $p = .004$, respectively). Internet gaming was significantly more prevalent among man with PPIU than in those with AIU ($p < .001$).

Correlation analyses revealed that the duration of weekly Internet use, attentional impulsiveness, motor impulsiveness, and total impulsiveness had significant and positive relationships with IAT scores among both women and men (Table 5). However, non-planning impulsiveness correlated positively with IAT scores in women only. For men, age, 2D:4D ratios on the right hand, and those on the left hand, correlated negatively with IAT scores (Figure 1).

The multiple linear regression analyses were undertaken for men and women separately including only 2D:4D ratios on the right hand to avoid multicollinearity. The multiple linear regression analyses revealed that age, duration of weekly Internet use, attentional impulsiveness, motor impulsiveness, and 2D:4D ratios on the right hand were independently associated with Internet addiction severity (i.e., IAT scores) (Table 6). However, total impulsiveness and 2D:4D ratios on the left hand were not independently associated with Internet addiction severity.

Moderated mediation analyses showed that gender moderated the relationship between 2D:4D ratios on the right hand and PPIU ($B = -37.20$; $p < .001$; 95% CI = −51.92 to −22.48), but not between right-hand 2D:4D ratios and BIS-11 ($B = -14.73$; $p = .55$; 95% CI = −63.03 to 33.57) or BIS-11 and PPIU ($B = -0.02$; $p = .37$; 95% CI = −0.05 to 0.02). 2D:4D ratios on the right hand had no significant indirect effects on PPIU through BIS-11 in men ($B = -0.94$; 95% CI = −3.18 to 0.43) or in women ($B = -0.42$; 95% CI = −2.57 to 1.63) (Figure 2). The index of moderated mediation (index = −0.53; 95% CI = −3.36 to 2.13) indicated the indirect effects through BIS-11 were not different between men and women.

Similarly, analyses using 2D:4D ratios on the left hand as the independent variable showed that gender moderated the relationship between 2D:4D ratios on the left hand and PPIU ($B = -15.38$; $p = .02$; 95% CI = −28.11 to −2.65), but not between left-hand 2D:4D ratios and BIS-11 ($B = -1.40$; $p = .96$; 95% CI = −53.39 to 50.59) or BIS-11 and PPIU ($B = -0.02$; $p = .26$; 95% CI = −0.05 to 0.01). 2D:4D ratios on the left hand had no significant indirect effect on PPIU through BIS-11 in men ($B = -0.99$; 95% CI = −3.48 to.38) or in women ($B = -1.40$; 95% CI = −3.79 to 0.59) (Figure 3). The index of moderated mediation (index = 0.41; 95% CI = −2.57 to 3.18) indicated no between-gender differences in the indirect effects through BIS-11.

DISCUSSION

In this study, we sought to examine associations between 2D:4D ratios and PPIU and how they related to gender and impulsivity. We report five main findings. First, students with PPIU had lower 2D:4D ratios than those with AIU, consistent with our a priori hypotheses. Second, participants who used the Internet mostly for online gaming had low 2D:4D ratios on the right hand. Third, the relationship between 2D:4D ratio and Internet addiction severity among women was not as strong as that seen among men, consistent with our a priori hypotheses. Fourth, the 2D:4D ratios on the right hand were independently related to PPIU among men, even after controlling for age and impulsivity. Fifth, in a moderated mediation analysis, the relationship between 2D:4D ratios and PPIU was not mediated through impulsivity as assessed by BIS-11, but it was moderated by gender. These findings suggest that the 2D:4D ratio may reflect contributions to PPIU above and beyond those linked to impulsivity, and that the relationship between 2D:4D ratios and PPIU does not operate through increased impulsivity.

These findings lend support to previous studies which indicate that alcohol abuse may be related to more masculinized (lower) 2D:4D ratios (Han et al., 2016; Kornhuber et al., 2011; Manning & Fink, 2011). The only study that examined the 2D:4D of individuals with a non-substance-related addictive disorder (i.e., video-game addiction) was from Germany (Kornhuber et al., 2013). The authors found that participants who were in the at-risk or addicted category according to the Video Game Addiction Scale (CSAS-II) ($n = 27$) exhibited lower 2D:4D ratios on both hands than those who did not exhibit problematic video-gaming ($n = 27$). The study (Kornhuber et al., 2013), however, included only men and the sample size was relatively small. Our results are in good agreement with those reported by Kornhuber et al. (2013), showing that men with PPIU had lower 2D:4D ratios on both hands when compared with same-sex individuals with AIU. However, women with PPIU and those with AIU did not differ with respect to 2D:4D ratio. Furthermore, IAT scores correlated negatively with both right- and left-hand 2D:4D ratios among men, whereas no such correlation was observed among women. According to our findings and those of Kornhuber et al. (2013),

Table 4. Comparison of women and men with and without PPIU

		Females ($n = 369$)							Males ($n = 283$)						
		AIU ($n = 319$)		PPIU ($n = 50$)		T-score or χ^2 value	Effect size (d)	p values	AIU ($n = 231$)		PPIU ($n = 52$)		T-score or χ^2 value	Effect size (d)	p values
		Mean	*SD*	Mean	*SD*				Mean	*SD*	Mean	*SD*			
Age (years)[a]		20.6	2.1	19.8	1.6	2.553	0.27	.011	21.2	2.2	20.9	2.3	0.761	0.09	.447
Duration of weekly Internet use (hr/week)[a]		21.9	13.2	34.9	18.2	−6.110	0.64	<.001	21.4	13.4	34.6	15.2	−6.214	0.74	<.001
Attentional impulsiveness (BIS-11) score[a]		16.1	4.9	20.4	4.0	−5.953	0.62	<.001	16.6	4.7	18.6	5.1	−2.628	0.31	.009
Motor impulsiveness (BIS-11) score[a]		18.3	5.5	22.5	7.1	−4.847	0.51	<.001	18.8	4.9	22.9	6.5	−5.060	0.60	<.001
Non-planning impulsiveness (BIS-11) score[a]		22.2	5.5	24.2	5.9	−2.323	0.24	.021	22.8	5.5	22.8	5.6	−0.031	0.06	.975
Total impulsiveness (BIS-11) score[a]		56.6	12.5	67.2	12.4	−5.590	0.58	<.001	58.2	11.3	64.3	12.8	−3.408	0.41	.001
Right-hand 2D:4D ratio[a]		1.001	0.038	1.017	0.039	−1.491	0.16	.137	0.996	0.033	0.969	0.028	5.451	0.62	<.001
Left-hand 2D:4D ratio[a]		0.996	0.038	0.998	0.036	−0.336	0.04	.737	0.993	0.346	0.978	0.034	2.910	0.35	.004
Most frequent Internet activities ($n = 560$)[b]	Social networking	161 (50.8%)		32 (64%)		12.694		.005	108 (47.2%)		14 (26.9%)		55.608		<.001
	Streaming videos	114 (35.7%)		13 (26%)					69 (30.1%)		10 (19.2%)				
	Gaming	6 (1.9%)		4 (8%)					19 (8.3%)		26 (50%)				
	Others	38 (11.9%)		1 (2%)					33 (14.4%)		2 (3.8%)				

Note. AIU: adaptive Internet use; BIS-11: Barratt Impulsivity Scale, version 11; PPIU: problematic and pathological Internet use.
[a]Student's t-test. [b]χ^2 test.

Table 5. Bivariate correlations between continuous variables among women and men

	Females ($n = 369$)								Males ($n = 283$)							
	2	3	4	5	6	7	8	9	2	3	4	5	6	7	8	9
1. Age (years)	−0.128*	−0.067	−0.001	0.013	−0.021	−0.010	0.059	−0.064	−0.029	−0.032	0.007	−0.052	−0.035	0.087	0.046	−0.182**
2. Duration of weekly Internet use (hr/week)		0.137*	0.213**	0.038	0.167**	−0.026	−0.099	0.433**		0.097	0.165**	0.054	0.142*	−0.103	0.002	0.422**
3. Attentional impulsiveness			0.483**	0.366**	0.769**	0.010	−0.038	0.420**			0.391**	0.341**	0.748**	−0.036	0.039	0.243**
4. Motor impulsiveness				0.389**	0.815**	−0.008	−0.046	0.331**				0.299**	0.761**	−0.088	−0.156**	0.280**
5. Non-planning impulsiveness					0.754**	−0.047	−0.074	0.179**					0.739**	−0.014	−0.037	0.035
6. Total impulsiveness						−0.020	−0.068	0.393**						−0.062	−0.074	0.247**
7. Right-hand 2D:4D ratio							0.588**	0.011							0.533**	−0.353**
8. Left-hand 2D:4D ratio								−0.033								−0.192**
9. Internet Addiction Test																

*Correlation is significant at the 0.05 level (two-tailed). **Correlation is significant at the 0.01 level (two-tailed).

we suggest that the amount of prenatal androgen exposure, as reflected in the 2D:4D ratios may be associated with a predisposition to certain types of non-substance-related addictive disorders among men. However, this association may be weaker among women.

In a prior study (Kornhuber et al., 2013), 2D:4D ratios on both hands in men were independently associated with video-game addiction when controlling for anxiety, depression, ADHD, hostility, and interpersonal sensitivity. However, we found that the 2D:4D ratio on the left hand was not independently associated with PPIU severity in men after including age, the duration of weekly Internet use, and impulsivity in multiple linear regression analyses. Furthermore, our findings were related to an integrated model wherein the path of 2D:4D ratios on the right hand to PPIU was not mediated by impulsive tendencies and was moderated by gender, indicating that only among men lower 2D:4D ratios were related to PPIU. Differences between the results of the two studies may reflect several factors including assessment of different behavioral addictions, cultural differences, the methods used to assess 2D:4D ratios, different potentially confounding variables considered in regression analyses, and the relatively small sample size of the prior study (Kornhuber et al., 2013). Interestingly, a meta-analysis (Hönekopp & Watson, 2010) concluded that the 2D:4D ratio on the right hand might be a better indicator of prenatal testosterone exposure than the 2D:4D ratio on the left-hand, which may serve as an explanation as to why only the right-hand 2D:4D ratios were independently associated with PPIU in our study. Taken together, we propose that a low 2D:4D ratio on the right hand, which may reflect the degree of fetal testosterone exposure, is an important statistical predictor of PPIU in men. Further study is needed to understand how fetal testosterone exposure may relate to brain structure and function that may predispose individuals to PPIU and other addictive behaviors.

Prenatal hormonal environment has long been recognized as an important factor regulating brain development (Grimshaw, Bryden, & Finegan, 1995). Few researchers, however, have addressed the effects of fetal androgen levels on the anatomy or the function of the brain. A prospective functional magnetic resonance imaging (fMRI) study (Lombardo, Ashwin, Auyeung, Chakrabarti, Lai, et al., 2012) has shown that fetal testosterone may influence the organization of reward-related regions including the caudate, putamen, and nucleus accumbens. In another study of 28 healthy boys (Lombardo, Ashwin, Auyeung, Chakrabarti, Taylor, et al., 2012), prenatal testosterone levels were positively associated with gray-matter volumes, particularly in the right temporo-parietal junction/posterior superior temporal sulcus and left amygdala. Differences in activation of the right temporo-parietal junction have also been reported among men with and without Internet addiction in a ball-throwing animation task (Kim et al., 2012). Furthermore, men with Internet gaming disorder exhibited altered gray-matter density and functional connectivity of the amygdala during fMRI at rest (Ko et al., 2015). These studies suggest neural mechanisms for the relationship between prenatal testosterone levels and addictive behaviors, in particular, Internet addiction among men. Our study is consistent with the notion

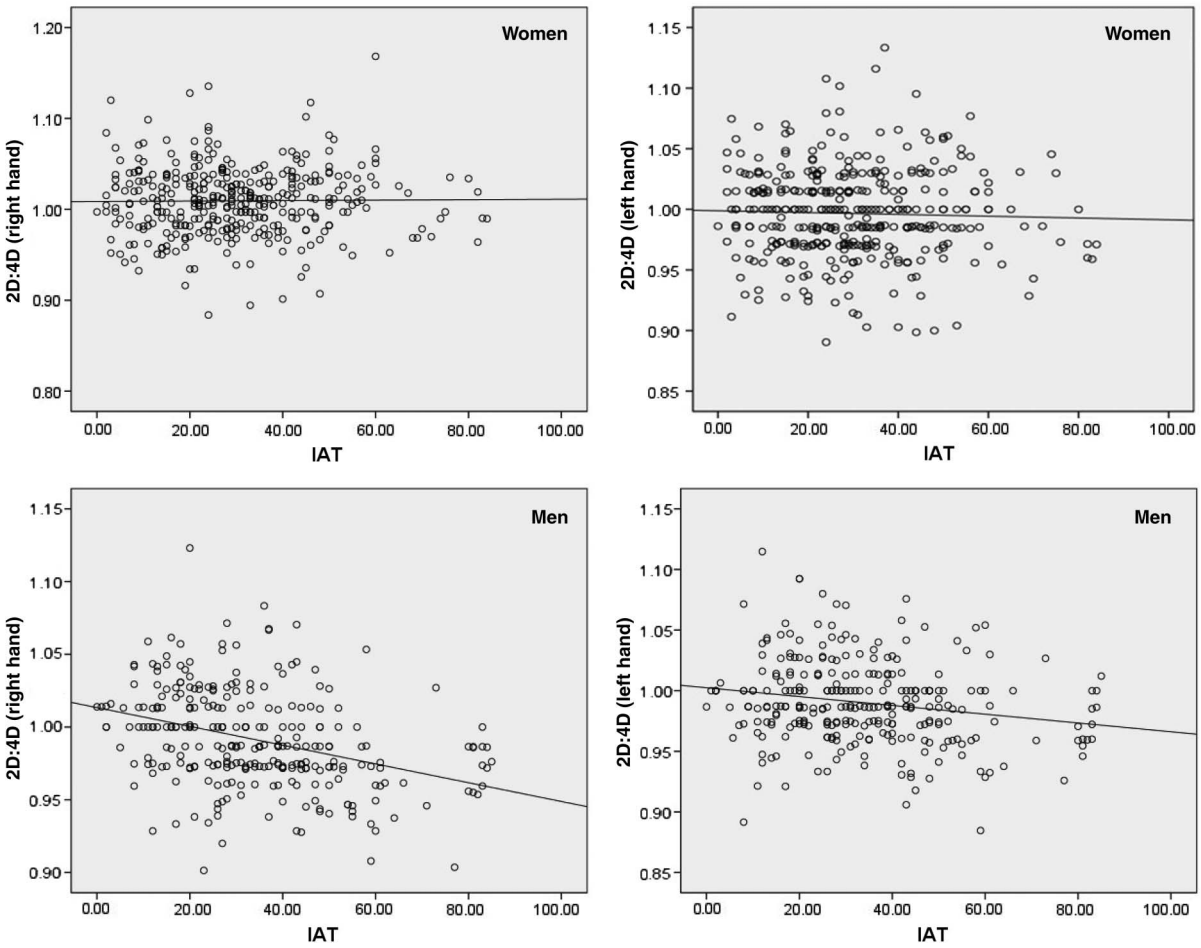

Figure 1. Scatter diagrams of the correlations between the IAT and 2D:4D ratios in women and men

Table 6. Multiple linear regression analysis with IAT as the dependent variable

		B	*t* values	95% CI	*p* values	R^2 model
Men	Age (years)	−0.148	−3.052	−2.069 to −0.446	.002	.324
	Duration of weekly Internet use (hr/week)	0.352	7.118	0.320 to 0.564	<.001	
	Total impulsiveness (BIS-11)	−0.216	−1.895	0.116 to 0.423	.001	
	Right-hand 2D:4D ratio	−0.274	−4.661	−213.741 to −106.498	<.001	
Women	Age (years)	−0.008	−0.187	−0.799 to −0.655	.852	.286
	Duration of weekly Internet use (hr/week)	0.378	8.388	0.333 to 0.536	<.001	
	Total impulsiveness (BIS-11)	0.330	7.380	0.314 to 0.541	<.001	
	Right-hand 2D:4D ratio	0.028	0.628	−26.354 to 51.109	.530	

Note. B: standardized coefficients; CI: confidence interval; R^2: percentage of total variance explained in the model.

that fetal testosterone exposure, as assessed indirectly by 2D:4D ratios, is associated with PPIU, particularly among men.

Internet gaming disorder, which has been included in section III of the DSM-5 (American Psychiatric Association, 2013), is arguably the most well-studied problematic Internet use behavior (Petry & O'Brien, 2013). In this study, the duration of weekly Internet use was longest in participants who used the Internet mostly for gaming. Furthermore, students with PPIU were more likely to report gaming as their most frequent Internet activity. Although we did not assess Internet gaming disorder by a validated instrument, online gaming activity may be considered as the one most likely to be related to PPIU in this population. We found that men whose most frequent online activity was Internet gaming exhibited lower 2D:4D ratios on the right hand when compared with those who used the Internet most frequently for online social networking and video streaming. According to this finding, a specific type of Internet addiction, namely Internet gaming disorder, might be most closely related to *in utero* testosterone levels among men. However, studies directly focusing on Internet gaming disorder should be conducted to draw more definitive conclusions.

A relationship between Internet addiction and impulsivity has been previously reported. For example, among

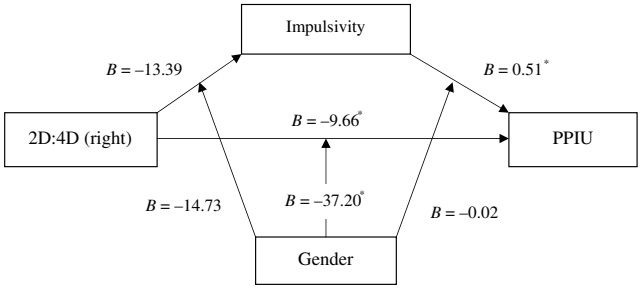

Figure 2. Path coefficient analysis of the relationship between 2D:4D ratio on the right hand, impulsivity (BIS-11 total score), gender, and PPIU. *$p < .01$

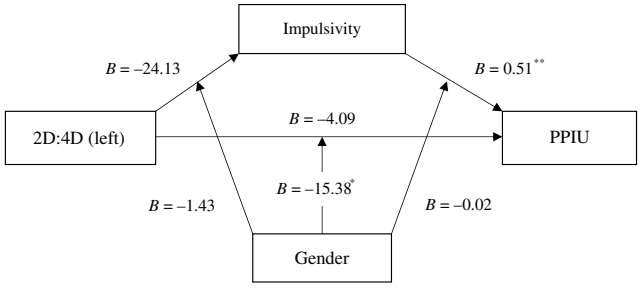

Figure 3. Path coefficient analysis of the relationship between 2D:4D ratio on the left hand, impulsivity (BIS-11 total score), gender, and PPIU. *$p < .05$. **$p < .01$

2,620 high-school students, means for all three subscales of the BIS-11 were higher in students with Internet addiction than in those without (Cao, Su, Liu, & Gao, 2007). Two studies (Lee et al., 2012; Zhou, Zhou, & Zhu, 2016) using similar methodologies found similar results. Interestingly, impulsivity levels of individuals with Internet addiction were comparable to those in individuals with pathological gambling, suggesting a role for impulsivity in both Internet addiction and pathological gambling (Lee et al., 2012; Zhou et al., 2016). Choi et al. (2013) have also shown that 23 subjects who scored 70 or higher on the IAT had higher scores on all three subscales of the BIS-11 than 24 sex-, age-, and intelligence-matched healthy comparison subjects. In this study, in line with existing research, individuals with PPIU exhibited higher impulsivity, as measured by the BIS-11 and as compared with individuals with AIU. However, non-planning impulsiveness scores were not different between men with PPIU and men with AIU. Thus, attentional impulsiveness (reflecting reduced attention toward stimuli) and motor impulsiveness (reflecting less forethought before acting) are associated with tendencies to use the Internet problematically across both gender groups. However, non-planning impulsiveness, which indicates lack of forward planning and provision, may be a risk factor for PPIU only among women. Moreover, regression analysis revealed that attentional impulsiveness and motor impulsiveness (but not non-planning impulsiveness and total impulsiveness) were independently associated with IAT scores among men, indicating that cognitive and motor aspects of the impulsivity construct may be particularly relevant to the relationship between impulsivity and Internet addiction. However, the relationship between 2D:4D ratios and PPIU does not appear to operate via impulsivity.

Strengths and limitations

Strengths of the present investigation include its relatively large sample size and the performance of two consecutive measurements of 2D:4D ratios conducted by two independent assessors. Several limitations should also be noted. First, although using a digital Vernier caliper to measure 2D:4D is an acceptable method (Ribiero, Neave, Morais, & Manning, 2016), simultaneously scanning participants' hands would offer an opportunity to conduct reliability analyses. Second, 2D:4D ratios may be influenced not only by prenatal testosterone exposure but also by genetic factors (Gobrogge et al., 2008; Medland et al., 2010; Paul et al., 2006; Voracek & Dressler, 2007, 2009). Thus, individual differences in terms of 2D:4D ratios may reflect genetic factors as well as *in utero* testosterone levels. Third, we assessed PPIU by use of a standardized self-report instrument rather than by a diagnostic interview. Fourth, more fine-grained assessments of Internet use were not collected in this study. Fifth, because of the relatively small number of individuals with pathological Internet use, we could only examine differences related to PPIU as a whole. Sixth, we did not evaluate other possible confounding factors, such as ADHD (Stevenson et al., 2007) and depression (Martin et al., 1999), which could affect the relationships between 2D:4D ratios and IAT scores.

CONCLUSIONS

This study, we believe for the first time, has linked PPIU to 2D:4D ratios in a sample of both women and men. This relationship appeared stronger in men than in women. Our results revealed that 2D:4D ratios on the right hand, which may represent a better indicator of *in utero* testosterone levels than 2D:4D ratios on the left hand (Grimshaw et al., 1995), were inversely correlated with Internet addiction severities even after controlling for individual differences in age, duration of weekly Internet use, and impulsivity. Moreover, the association between 2D:4D ratios on the right hand and PPIU was moderated by gender, with lower 2D:4D ratios related to PPIU only in men. We propose that one of the long-term consequences of exposure to greater levels of fetal testosterone may be an increased vulnerability to specific addictions, and PPIU in particular. The link between high *in utero* testosterone and PPIU is unknown, but men with low 2D:4D ratios may show greater reward sensitivity than men with high 2D:4D ratios, and thus reward sensitivity might link 2D:4D ratios and PPIU (Lombardo, Ashwin, Auyeung, Chakrabarti, Lai, et al., 2012). Nevertheless, longitudinal studies are needed to investigate directly this possibility. Measuring fetal testosterone from amniotic fluid samples and following participants after delivery until their early adulthood would provide more robust evidence of the effect of fetal testosterone on the development of PPIU and addictive disorders more generally. Our findings should be replicated using larger samples and focusing on specific problematic Internet use behaviors, in particular, Internet

gaming disorder. Future studies should combine neuroimaging methods, genetic assessments, and 2D:4D measurements to facilitate an understanding of brain factors that may relate to 2D:4D ratios and PPIU.

Funding sources: MNP's involvement in this work was supported by The National Center on Addiction and Substance Abuse and a Center of Excellence in Gambling Research Award from the National Center for Responsible Gaming. The funding agencies had no role in study design; data collection, analysis, and interpretation; preparation of the manuscript; or the decision to submit the paper for publication.

Authors' contribution: FC, SK, MD, AME, EK, NBT, and MK designed the study and wrote the protocol. SK conducted literature searches and provided summaries of previous research studies. FC and ZWZ conducted the statistical analysis. FC wrote the first draft of the manuscript. MNP and S-KL actively provided feedback and helped develop the manuscript. All authors contributed to and have approved the final version of manuscript. MK and MNP are equal senior authors.

Conflict of interest: FC, SK, MD, AME, EK, NBT, S-KL, MNP, and MK declare that they have no conflict of interest with respect to the content of this manuscript. MNP has consulted for and advised Lundbeck, Ironwood, Shire, INSYS, RiverMend Health, Opiant/Lakelight Therapeutics, and Jazz Pharmaceuticals; has received research support from the National Institutes of Health, Veteran's Administration, Mohegan Sun Casino, the National Center for Responsible Gaming and its affiliated Institute for Research on Gambling Disorders, and Pfizer; has participated in surveys, mailings, or telephone consultations related to drug addiction, impulse control disorders, or other health topics; has consulted for law offices and the federal public defender's office in issues related to impulse control disorders; provides clinical care in the Connecticut Department of Mental Health and Addiction Services Problem Gambling Services Program; has performed grant reviews for the National Institutes of Health and other agencies; has guest-edited journal sections; given academic lectures in grand rounds, CME events, and other clinical/scientific venues; and has generated books or chapters for publishers of mental health texts. Other authors report no disclosures. The views presented in this manuscript represent those of the authors and not necessarily those of the funding agencies who had no input into the content of the manuscript.

REFERENCES

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5* (5th ed.). Washington, DC: American Psychiatric Association.

Bailey, A. A., & Hurd, P. L. (2005). Finger length ratio (2D:4D) correlates with physical aggression in men but not in women. *Biological Psychology, 68,* 215–222. doi:10.1016/j.biopsycho.2004.05.001

Borkowska, B., & Pawlowski, B. (2013). Alcohol and nicotine intake and prenatal level of androgens measured by digit ratio. *Personality and Individual Differences, 55,* 685–687. doi:10.1016/j.paid.2013.05.020

Boysan, M., Kuss, D. J., Barut, Y., Ayköse, N., Güleç, M., & Özdemir, O. (2017). Psychometric properties of the Turkish version of the Internet Addiction Test (IAT). *Addictive Behaviors, 64,* 247–252. doi:10.1016/j.addbeh.2015.09.002

Cao, F., Su, L., Liu, T., & Gao, X. (2007). The relationship between impulsivity and Internet addiction in a sample of Chinese adolescents. *European Psychiatry, 22,* 466–471. doi:10.1016/j.eurpsy.2007.05.004

Choi, J. S., Park, S. M., Roh, M. S., Lee, J. Y., Park, C. B., Hwang, J. Y., Gwak, A. R., & Jung, H. Y. (2014). Dysfunctional inhibitory control and impulsivity in Internet addiction. *Psychiatry Research, 215,* 424–428. doi:10.1016/j.psychres.2013.12.001

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Collinson, S. L., Lim, M., Chaw, J. H, Verma, S., Sim, K., Rapisarda, A., & Chong, S. A. (2010). Increased ratio of 2nd to 4th digit (2D:4D) in schizophrenia. *Psychiatry Research, 176,* 8–12. doi:10.1016/j.psychres.2009.08.023

Fink, B., Neave, N., & Manning, J. T. (2003). Second to fourth digit ratio, body mass index, waist-to-hip ratio, and waist-to-chest ratio: Their relationships in heterosexual men and women. *Annals of Human Biology, 30,* 728–38. doi:10.1080/03014460310001620153

Gobrogge, K. L., Breedlove, S. M., & Klump, K. L. (2008). Genetic and environmental influences on 2D:4D finger length ratios: A study of monozygotic and dizygotic male and female twins. *Archives of Sexual Behavior, 37,* 112–118. doi:10.1007/s10508-007-9272-2

Gorka, A. X., Norman, R. E., Radtke, S. R., Carré, J. M., & Hariri, A. R. (2015). Anterior cingulate cortex gray matter volume mediates an association between 2D:4D ratio and trait aggression in women but not men. *Psychoneuroendocrinology, 56,* 148–156. doi:10.1016/j.psyneuen.2015.03.004

Grimshaw, G. M., Bryden, M. P., & Finegan, J. K. (1995). Relations between prenatal testosterone and cerebral lateralization in children. *Neuropsychology, 9,* 68–79. doi:10.1037/0894-4105.9.1.68

Gulec, H., Tamam, L., Gulec, M. Y., Turhan, M., Karakus, G., Zengin, M., & Stanford, M. S. (2008). Psychometric properties of the Turkish version of the Barratt Impulsiveness Scale-11. *Klinik Psikofarmakoloji Bulteni – Bulletin of Clinical Psychopharmacology, 18,* 251–258.

Han, C., Bae, H., Lee, Y. S., Won, S. D., & Kim, D. J. (2016). The ratio of 2nd to 4th digit length in Korean alcohol-dependent patients. *Clinical Psychopharmacology and Neuroscience, 14,* 148–152. doi:10.9758/cpn.2016.14.2.148

Hanoch, Y., Gummerum, M., & Rolison, J. (2012). Second-to-fourth digit ratio and impulsivity: A comparison between offenders and nonoffenders. *PLoS One, 7,* e47140. doi:10.1371/journal.pone.0047140

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York, NY: Guilford Press.

Hayes, A. F. (2015). An index and test of linear moderated mediation. *Multivariate Behavioral Research, 50,* 1–22. doi:10.1080/00273171.2014.962683

Hönekopp, J., & Watson, S. (2010). Meta-analysis of digit ratio 2D:4D shows greater sex difference in the right hand. *American Journal of Human Biology, 22,* 619–630. doi:10.1002/ajhb.21054

Kim, Y. R., Son, J. W., Lee, S. I., Shin, C. J., Kim, S. K., Ju, G., Choi, W. H., Oh, J. H., Lee, S., Jo, S., & Ha, T. H. (2012). Abnormal brain activation of adolescent Internet addict in a ball-throwing animation task: Possible neural correlates of disembodiment revealed by fMRI. *Progress in Neuro-Psychopharmacology & Biological Psychiatry, 39,* 88–95. doi:10.1016/j.pnpbp.2012.05.013

Ko, C. H., Hsieh, T. J., Wang, P. W., Lin, W. C., Yen, C. F., Chen, C. S., & Yen, J. Y. (2015). Altered gray matter density and disrupted functional connectivity of the amygdala in adults with Internet gaming disorder. *Progress in Neuro-Psychopharmacology & Biological Psychiatry, 57,* 185–192. doi:10.1016/j.pnpbp.2014.11.003

Kornhuber, J., Erhard, G., Lenz, B., Kraus, T., Sperling, W., Bayerlein, K., Biermann, T., & Stoessel, C. (2011). Low digit ratio 2D:4D in alcohol dependent patients. *PLoS One, 6,* e19332. doi:10.1371/journal.pone.0019332

Kornhuber, J., Zenses, E. M., Lenz, B., Stoessel, C., Bouna-Pyrrou, P., Rehbein, F., Kliem, S., & Mößle, T. (2013). Low 2D:4D values are associated with video game addiction. *PLoS One, 8,* e79539. doi:10.1371/journal.pone.0079539

Lee, H. W., Choi, J. S., Shin, Y. C., Lee, J. Y., Jung, H. Y., & Kwon, J. S. (2012). Impulsivity in Internet addiction: A comparison with pathological gambling. *Cyberpsychology, Behavior, and Social Networking, 15,* 373–377. doi:10.1089/cyber.2012.0063

Lombardo, M. V., Ashwin, E., Auyeung, B., Chakrabarti, B., Lai, M. C., Taylor, K., Hackett, G., Bullmore, E. T., & Baron-Cohen, S. (2012). Fetal programming effects of testosterone on the reward system and behavioral approach tendencies in humans. *Biological Psychiatry, 72,* 839–847. doi:10.1016/j.biopsych.2012.05.027

Lombardo, M. V., Ashwin, E., Auyeung, B., Chakrabarti, B., Taylor, K., Hackett, G., Bullmore, E. T., & Baron-Cohen, S. (2012). Fetal testosterone influences sexually dimorphic gray matter in the human brain. *Journal of Neuroscience, 32,* 674–680. doi:10.1523/JNEUROSCI.4389-11.2012

Lutchmaya, S., Baron-Cohen, S., Raggatt, P., Knickmeyer, R., & Manning, J. T. (2004). 2nd to 4th digit ratios, fetal testosterone and estradiol. *Early Human Development, 77,* 23–28. doi:10.1016/j.earlhumdev.2003.12.002

Malas, M. A., Dogan, S., Evcil, E. H., & Desdicioglu, K. (2006). Fetal development of the hand, digits and digit ratio (2D:4D). *Early Human Development, 82,* 469–475. doi:10.1016/j.earlhumdev.2005.12.002

Manning, J. T., Barley, L., Walton, J., Lewis-Jones, D. I., Trivers, R. L., Singh, D., Thornhill, R., Rohde, P., Bereczkei, T., Henzi, P., Soler, M., & Szwed, A. (2000). The 2nd:4th digit ratio, sexual dimorphism, population differences, and reproductive success: Evidence for sexually antagonistic genes? *Evolution and Human Behavior, 21,* 163–183. doi:10.1016/S1090-5138(00)00029-5

Manning, J. T., Baron-Cohen, S., Wheelwright, S., & Sanders, G. (2001). The 2nd to 4th digit ratio and autism. *Developmental Medicine & Child Neurology, 43,* 160–164. doi:10.1111/j.1469-8749.2001.tb00181.x

Manning, J. T., Bundred, P. E., Newton, D. J., & Flanagan, B. F. (2003). The second to fourth digit ratio and variation in the androgen receptor gene. *Evolution and Human Behavior, 24,* 399–405. doi:10.1016/S1090-5138(03)00052-79

Manning, J. T., & Fink, B. (2008). Digit ratio (2D:4D), dominance, reproductive success, asymmetry, and sociosexuality in the BBC Internet Study. *American Journal of Human Biology, 20,* 451–461. doi:10.1002/ajhb.20767

Manning, J. T., & Fink, B. (2011). Digit ratio, nicotine and alcohol intake and national rates of smoking and alcohol consumption. *Personality and Individual Differences, 50,* 344–348. doi:10.1016/j.paid.2010.10.016

Manning, J. T., & Taylor, R. P. (2001). Second to fourth digit ratio and male ability in sport: Implications for sexual selection in humans. *Evolution and Human Behavior, 22,* 61–69. doi:10.1016/S1090-5138(00)00063-5

Manning, J. T., Trivers, R. L., Thornhill, R., & Singh, D. (2000). The 2nd:4th digit ratio and asymmetry of hand performance in Jamaican children. *Laterality, 5,* 121–132. doi:10.1080/135765000396744

Martin, S. M., Manning, J. T., & Dowrick, C. F. (1999). Fluctuating asymmetry, relative digit length, and depression in men. *Evolution and Human Behavior, 20,* 203–214. doi:10.1016/S1090-5138(99)00006-9

McFadden, D., & Shubel, E. (2002). Relative lengths of fingers and toes in human males and females. *Hormones and Behavior, 42,* 492–500. doi:10.1006/hbeh.2002.1833

Medland, S. E., Zayats, T., Glaser, B., Nyholt, D. R., Gordon, S. D., Wright, M. J., Montgomery, G. W., Campbell, M. J., Henders, A. K., Timpson, N. J., Peltonen, L., Wolke, D., Ring, S. M., Deloukas, P., Martin, N. G., Smith, G. D., & Evans, D. M. (2010). A variant in LIN28B is associated with 2D:4D finger-length ratio, a putative retrospective biomarker of prenatal testosterone exposure. *American Journal of Human Genetics, 86,* 519–525. doi:10.1016/j.ajhg.2010.02.017

Ngai, S. S. (2012). Exploring the validity of the Internet addiction test for students in grades 5-9 in Hong Kong. *International Journal of Adolescence and Youth, 13,* 221–237. doi:10.1080/02673843.2007.9747976

Okten, A., Kalyoncu, M., & Yariş, N. (2002). The ratio of second- and fourth-digit lengths and congenital adrenal hyperplasia due to 21-hydroxylase deficiency. *Early Human Development, 70,* 47–54. doi:10.1016/S0378-3782(02)00073-7

Patton, J., Stanford, M., & Barratt, E. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51,* 151–184. doi:10.1002/1097-4679(199511)51:6<768:AID-JCLP2270510607>3.0.CO

Paul, S. N., Kato, B. S., Cherkas, L. F., Andrew, T., & Spector, T. D. (2006). Heritability of the second to fourth digit ratio (2D:4D): A twin study. *Twin Research and Human Genetics, 9,* 215–219. doi:10.1375/183242706776382491

Petry, N. M, & O'Brien, C. P. (2013). Internet gaming disorder and the DSM-5. *Addiction, 108,* 1186–1187. doi:10.1111/add.12162

Quinton, S. J., Smith, A. R., & Joiner, T. (2011). The 2nd to 4th digit ratio (2D:4D) and eating disorder diagnosis in women. *Personality and Individual Differences, 51,* 402–405. doi:10.1016/j.paid.2010.07.024

Ribiero, E., Neave, N., Morais, R. N., & Manning, J. T. (2016). Direct versus indirect measurement of digit ratio (2D:4D): A critical review of the literature and new data. *Evolutionary Psychology, 14,* 1–8. doi:10.1177/1474704916632536

Smith, A. R., Hawkeswood, S. E., & Joiner, T. E. (2010). The measure of a man: Associations between digit ratio and disordered eating in males. *International Journal of Eating Disorders, 43,* 543–548. doi:10.1002/eat.20736

Stevenson, J. C., Everson, P. M., Williams, D. C., Hipskind, G., Grimes, M., & Mahoney, E. R. (2007) Attention deficit/hyperactivity disorder (ADHD) symptoms and digit ratios in a college sample. *American Journal of Human Biology, 19,* 41–50. doi:10.1002/ajhb.20571

Verdejo-García, A., Lawrence, A. J., & Clark, L. (2008). Impulsivity as a vulnerability marker for substance-use disorders: Review of findings from high-risk research, problem gamblers and genetic association studies. *Neuroscience & Biobehavioral Reviews, 32,* 777–810. doi:10.1016/j.neubiorev.2007.11.003

Verster, J. C., & de Haan, L. (2011). The 2D:4D digit ratio: A biomarker of alcohol and drug abuse? *Current Drug Abuse Reviews, 4,* 65–66. doi:10.2174/1874473711104020065

von Diemen, L., Bassani, D. G., Fuchs, S. C, Szobot, C. M., & Pechansky, F. (2008). Impulsivity, age of first alcohol use and substance use disorders among male adolescents: A population based case-control study. *Addiction, 103,* 1198–1205. doi:10.1111/j.1360-0443.2008.02223.x

Voracek, M., & Dressler, S. G. (2007). Digit ratio (2D:4D) in twins: Heritability estimates and evidence for a masculinized trait expression in women from opposite-sex pairs. *Psychological Reports, 100,* 115–126. doi:10.2466/pr0.100.1.115-126

Voracek, M., & Dressler, S. G. (2009). Brief communication: Familial resemblance in digit ratio (2D:4D). *American Journal of Physical Anthropology, 140,* 376–380. doi:10.1002/ajpa.21105

Voracek, M., Manning, J. T., & Dressler, S. G. (2007). Repeatability and interobserver error of digit ratio (2D:4D) measurements made by experts. *American Journal of Human Biology, 19,* 142–146. doi:10.1002/ajhb.20581

Williams, T. J., Pepitone, M. E., Christensen, S. E., Cooke, B. M., Huberman, A. D., Breedlove, N. J., Breedlove, T. J., Jordan, C. L., & Breedlove, S. M. (2000). Finger-length ratios and sexual orientation. *Nature, 404,* 455–456. doi:10.1038/35006555

Young, K. S. (1998). *Caught in the net*. New York, NY: John Wiley.

Young, K. S. (2017, January 30). *Internet Addiction Test (IAT)*. Retrieved from http://netaddiction.com/internet-addiction-test/

Zhou, Z., Zhou, H., & Zhu, H. (2016). Working memory, executive function and impulsivity in Internet-addictive disorders: A comparison with pathological gambling. *Acta Neuropsychiatrica, 28,* 92–100. doi:10.1017/neu.2015.54