Associations among behavioural inhibition and owner-rated attention,

hyperactivity/impulsivity, and personality in the domestic dog (*Canis familiaris*)

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47

48 **Abstract**

49 In humans, behavioural disinhibition is associated with attention-deficit/hyperactivity disorder

50 (ADHD). Limitations to rodent models of ADHD-like behaviours/symptoms (ADHD-B/S)

51 may be augmented by complementary ones, such as the domestic dog. We examined

52 associations between family dogs' (N=29; of 14 breeds and 12 mongrels) performance on a

53 self-developed touchscreen behavioural Go/No-Go paradigm and their owner-rated inattention

54 (IA) and hyperactivity/impulsivity (H/I), accounting for relevant covariates. A greater

55 proportion of commission errors was associated with greater H/I. Regardless of accuracy,

56 relative to dogs with no prior training, those with basic training had shorter response latencies.

57 Also regardless of accuracy, greater confidence and extraversion were associated with shorter

58 latencies, and greater openness was associated with longer latencies. Shorter latency to

59 commission errors was associated with greater IA. Findings support the dog as a model of the

60 association between behavioural inhibition and ADHD-B/S and are early evidence of

61 convergent validity between the behavioural paradigm and the rating scale measure in dogs.

62 *Keywords:* behavioural inhibition, inattention, hyperactivity/impulsivity, domestic dog,
63 Go/No-Go test

64   Associations among behavioural inhibition and owner-rated attention,

65   hyperactivity/impulsivity, and personality in the domestic dog (*Canis familiaris*)

66 In the cognitive- and/or neuropsychology literatures, behavioural or response inhibition is the

67 ability to suppress actions that are inappropriate or undesirable, given short-term adaptation

68 and long-term goals (Barkley, 1997; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006;

69 Nigg, 2001). Specifically, behavioural inhibition is definable as "three interrelated processes:

70 (a) inhibition of an initial, prepotent response to an event (inhibitory control); (b) stopping of

71 an ongoing response, which thereby permits a delay in the decision to respond; and (c) the

72 protection of this period of delay and the self-directed responses that occur within it from

73 disruption by competing events and responses (interference control)" (Barkley, 1997; p. 67).

74 The first two of these processes are also referred to as action restraint and action cancellation.

75 The former is typically probed in tasks such as the go/no-go paradigm, with the ability or failure

76 to withhold from responding as the outcome of interest (indexed by, e.g., percentage of

77 successful inhibition and commission errors, etc.). The latter is typically studied using the stop-

78 signal task, with the ability or failure to inhibit a motor response *during* its execution as the

79 outcome of interest (Eagle, Bari, & Robbins, 2008).

80   A large body of work indicates that deficient behavioural or response inhibition

81 (hereafter: behavioural inhibition) is a predisposing or risk factor for a range of psychological

82 and psychiatric disorders and negative outcomes. These include antisociality and disruptive

83 behaviour (Nigg, 2003; Oosterlaan & Sergeant, 1998; Swann, Lijffijt, Lane, Steinberg, &

84 Moeller, 2009; Young et al., 2009), alcohol and other drug misuse and dependence (Iacono,

85 Malone, & McGue, 2008; Nigg et al., 2006), borderline (Nigg, Silk, Stavro, & Miller, 2005)

86 and obsessive-compulsive traits (Bannon, Gonsalvez, Croft, & Boyce, 2002), as well as parent-

87 and teacher-rated social impairment in children (Bunford et al., 2015). Behavioural inhibition

88   has perhaps been most often linked to attention-deficit/hyperactivity disorder (ADHD)

89   (Barkley, 1997; Bunford et al., 2015).

90   Although ADHD incidence rates have increased, treatments have not correspondingly

91   advanced, potentially due to lack of appropriate animal models (Majdak et al., 2016). Several

92   animal – primarily rodent – models of ADHD – or, most appropriately, *ADHD-like behaviours*

93   *and symptoms* (hereafter: ADHD-B/S) (Sontag, Tucha, Walitza, & Lange, 2010) – have been

94   proposed and these range from ones with genetic manipulation to neurotoxic lesions (Sontag

95   et al., 2010). Although there is ample research on behavioural disinhibition (Kolokotroni,

96   Rodgers, & Harrison, 2011; Morgan, Einon, & Nicholas, 1975) and ADHD-B/S in rodents

97   (Adriani, Caprioli, Granstrem, Carli, & Laviola, 2003; Sagvolden et al., 2009), with results

98   generally indicating similar cognitive and neuropsychological mechanisms connecting these

99   phenomena as in humans (Fox, Hand, & Reilly, 2008), there are limitations to the rodent model.

100   For example, the dopamine transporter (DAT) knock-out mouse exhibits

101   neurochemical alterations irrelevant for modelling classical ADHD (Gainetdinov, 2010).

102   Spontaneously hypertensive rats (SHR) exhibit hypertension as a confounding factor

103   (Sagvolden, Russell, Aase, Johansen, & Farshbaf, 2005) and high levels of on-task behaviour

104   in fixed-interval/extinction paradigms despite clinical characterization of inattention

105   emphasizing off-task behaviour and distractibility (Alsop, 2007). Generally, rodents need fluid

106   and/or food restriction as a motivational tool relative to human voluntary participation and are

107   kept in a restricted laboratory environment as living space relative to the complex and variable

108   environment of human living spaces. These limit generalizability of rodent data.

109   A novel and promising animal model of human behaviour and cognition is the domestic

110   dog (*Canis familiaris*). First, dogs are interesting – in some aspects uniquely so – from an

111   ethological, comparative psychological perspective as certain adaptational processes during

112   their domestication have shaped their behavioral and socio-cognitive skills in a manner that

they are exceptionally able and motivated to competently interact with humans (Topál, Miklósi, et al., 2009). While in rodents most social interactions center around dominance, reproduction, and parental care, an evolutionarily new behavioral regulation system, one that organizes their social behaviors towards/with humans, has developed in dogs.

This makes the dog an ideal animal model of complex human processes, including cognitive and social ones. In support is a long line of research focused on phenomena related to canine behavior, cognition, and emotion, such as inequity aversion (Range, Horn, Viranyi, & Huber, 2009), automatic (Range, Huber, & Heyes, 2011) and selective imitation (Range, Viranyi, & Huber, 2007), reward processing (Gerencsér, Bunford, Moesta, & Miklósi, 2018), comprehension of pointing gestures (Lakatos, Soproni, Dóka, & Miklósi, 2009), and social referencing (Merola, Prato-Previde, & Marshall-Pescini, 2012). Further, dogs have been shown to exhibit spontaneous affiliative responses to human social stimuli, including in terms of attachment (Gácsi, Topál, Miklósi, Dóka, & Csányi, 2001) as well as preferential attention to the eyes of humans and early and specific sensitivity to establishing eye contact with humans (Gácsi et al., 2005), compulsory compliance in social situations (Topál, Gergely, Erdöhegyi, Csibra, & Miklósi, 2009), and an ability to adapt emotionally and physiologically to humans (indicated by emotional contagion; Sümegi, Olah, & Topál, 2014). Recently, in combination with or without behavioral approaches, neuroscience methods are used to study awake dog behavior, including reward-, visual- and vocal processing (e.g., Andics et al., 2016; Andics, Gácsi, Faragó, Kis, & Miklósi, 2014), memory consolidation (Kis et al., 2017) as well as canine sleep (e.g., Bunford et al., 2018; Iotchev, Kis, Bódizs, Van Luijtelaar, & Kubinyi, 2017; Kis et al., 2014; for review, see Bunford, Andics, Kis, Miklósi, & Gácsi, 2017).

With regard to ADHD B/S, dogs are a promising species for comparative research insofar as individual variation in these observable characteristics, if analogous to those observed in humans, would suggest that the observed phenotypic variability not only parallels

138 human behavior but is also relevant to better understanding the underlying genotypic or

139 biological variability. In this vein, dogs exhibit behaviors redolent of the repetitive and

140 stereotyped behaviors observed in youth with autism spectrum disorders, and the molecular

141 background of these behaviors is similar in the two species (Tsilioni et al., 2014). Researchers

142 have also identified canine genes for characteristics relevant to agility (Kim & Davis, 2018),

143 friendliness (VonHoldt et al., 2017), attachment (Kovács et al., 2018) and social behavior (Kis,

144 Bence, et al., 2014). As such, identification of further phenotypic parallels, including in

145 inhibition, may clarify the genetic basis of ADHD/BS not only in humans but also in dogs.

146   Second, dogs are interesting given their potential value as a model of human clinical

147 conditions, including ADHD B/S. Because dogs naturally exhibit (unlike rodents; Hejjas et al.,

148 2007) individual differences in inhibition and ADHD-B/S (Vas, Topál, Pech, & Miklósi, 2007;

149 Wright, Mills, & Pollux, 2011, 2012) and genetic polymorphisms relevant to ADHD-B/S (Wan

150 et al., 2013), their biological manipulation is unnecessary. Further, as dogs exhibit socio-

151 cognitive skills that share behavioural and functional characteristics with humans' (Miklósi &

152 Topál, 2013) and dogs share their physical and social environment with humans, they are a

153 suitable model for testing not only differences in ADHD-B/S but also relevant functional

154 outcomes (e.g., socio-cognitive skill deficits and social impairment; Bunford et al., 2015).

155 More generally, dogs' cooperativeness and trainability obviate the need for fluid and/or food

156 restriction, allowing them to have a physiological and social state in experiments comparable

157 to humans'. Indeed, behavioural paradigms (e.g., Topál, Miklósi, Csányi, & Dóka, 1998) and

158 rating scales (Lit, Schweitzer, Iosif, & Obermauer, 2010; Vas et al., 2007; Wright et al., 2012)

159 designed to assess human behaviour have been adapted to measure dog behaviour.

160   Studies on canine inhibition assess a characteristic related to behavioural inhibition,

161 cognitive inhibition, i.e., ability to tolerate delayed gratification (Riemer, Mills, & Wright,

162 2014; Wright et al., 2012). Similarly to humans, canine intolerance of delayed gratification is

163   stable (Riemer et al., 2014), and higher owner-rated impulsivity is associated with behavioural

164   manifestation of intolerance of delayed reward (Wright et al., 2012). Available studies on

165   differences in canine inattention (IA) and hyperactivity/impulsivity (H/I) rely solely on rating

166   scales and there are no studies on individual differences in canine *behavioural* inhibition and

167   its relation to ADHD-B/S.

168   To study these relationships in humans, behavioural paradigms of inhibition are

169   typically paired with rating scale measures of ADHD symptoms (e.g., Bunford et al., 2015).

170   One of the most commonly used of such paradigms is the Go/No-Go task (Votruba &

171   Langenecker, 2013). Youth with ADHD, relative to typically developing peers, consistently

172   exhibit more errors and slower response times on Go/No-Go tasks (Castellanos, Giedd,

173   Hamburger, Marsh, & Rapoport, 1996; Hartung, Milich, Lynam, & Martin, 2002; Vaidya et

174   al., 1998). Omission errors (when a behavioural response should be executed but is not) are

175   primarily associated with IA whereas commission errors (when a behavioural response should

176   not be executed [i.e., should be inhibited] but is) are primarily associated with H/I (Bezdjian,

177   Baker, Lozano, & Raine, 2009; Trommer, Hoeppner, Lorber, & Armstrong, 1988). As such,

178   the Go/No-Go task is relevant to probing behavioural inhibition and to assessing the association

179   between task performance and ADHD-B/S. It is ideal for comparative research as it is

180   appropriate for assessment of human and animal subjects without considerable alterations to

181   experimental or task design (Eagle, Bari, et al., 2008).

182   Differences in personality in both humans and in animals (including rodent models of

183   ADHD), are associated with differences in behavioural inhibition and/or ADHD; and, as such,

184   should be considered in designs involving these phenomena. For example, prior findings

185   indicate that agreeableness and extraversion are negatively whereas neuroticism is positively

186   associated with behavioural inhibition (Muris et al., 2009). Also, although agreeableness (low)

187   and neuroticism (low) are linked to ADHD, they are not specific to it (but are, rather, better

explained by comorbid psychopathologies) and the literature on the association between extraversion and ADHD is mixed (Nigg et al., 2002). Conversely, findings indicating that more severe ADHD symptoms are related to lower conscientiousness appear to reflect that this effect is unique to IA (Nigg et al., 2002) and is independent of co-occurring antisocial and delinquent behaviour (Nigg, Blaskey, et al., 2002). Similarly, increased aggression has been observed in association with behavioural disinhibition in the 5-HT1B serotonin receptor knockout mouse (Brunner & Hen, 1997; Nautiyal et al., 2015). Reduced levels of the serotonin metabolite 5-hydroxyindole acetic acid (5-HIAA) in mice (Caramaschi, de Boer, & Koolhaas, 2007) and primates (Mehlman et al., 1994) are associated with aggression and impulsivity. In fish and lizards, the onset of aggressive behavior is associated with increased serotonergic activity, whereas inhibition of aggression and social subordination are related to prolonged elevation of serotonin metabolism (Øverli, Harris, & Winberg, 2000; Stoddard, 2003; Summers et al., 2005). Finally, increased aggression and reactivity has been found in one rodent model of ADHD, the DAT knockout mouse (Rodriguiz, Chu, Caron, & Wetsel, 2004).

Current Study

Our primary aim in the current study was thus to examine associations among dogs' performance – as indexed by error rate and response time – on a self-developed touchscreen behavioural Go/No-Go test and their owner-rated IA and H/I and dimensions of personality on two widely-used rating scales, in an average population of animals (i.e., not selected for a certain level of inattention or hyperactivity/impulsivity).

Method

Participants and Procedures

Participants were 29 adult family dogs (M_{age} = 4.59 years, SD = 2.90) of 14 different breeds and 12 mongrels (3 intact female, 6 intact male, 13 spayed female, 7 neutered male). As the current study was the first of its kind, there were no prior data available to conduct a formal

213   power analysis and determine a necessary sample size. Our aim was thus to establish whether

214   an effect of any magnitude can be demonstrated. The sample of 29 dogs allowed for

215   simultaneously achieving feasibility in addressing our research questions and minimizing

216   burden of participation in case of both owners and their dogs (who had to participate in training

217   and testing, on average, on 18 occasions, see Canine Go/No-Go paradigm below). Differences

218   in training status were indexed as "none" (no training), "basic" (basic obedience training),

219   "intermediate" (higher level obedience training), or "advanced" (IPO Schutzhund, rescue,

220   service, or gun dog exam) and thus reflected differences in both cognitive and physical training

221   status. Seven dogs had none, 12 basic, 4 intermediate, and 6 advanced training. Owners and

222   their dogs were recruited through the Department of Ethology participant pool and website,

223   popular social networking sites, and via snowball sampling. All experimental procedures

224   (training and test, see *Canine go/no-go paradigm below*) took place at the Eötvös Loránd

225   University, Department of Ethology, in a 3 m × 6 m experimental room.

226   **Measures**

227   **Canine Go/No-Go paradigm.** In a basic sense (there are variations), Go/No-Go

228   paradigms involve two types of stimuli presented in some modality, e.g., auditorily or visually:

229   one stimulus, which is the "go" stimulus, is to be responded to with the execution of some form

230   of action or behaviour. The other stimulus, which is the "no-go" stimulus, is to be responded

231   to with the withholding of some form of prepotent action or behaviour. In case of the current

232   study, corresponding details are described below.

233   *Presentation and recording apparatus.* Dogs were trained to use a touchscreen device.

234   This comprised a 36 cm tall and 47 cm wide touchscreen (31.5 cm × 38.5 cm screen with a

235   1024 × 768 pixel resolution; ZYTRO-19; Novoparts, Budapest, Hungary) with integral

236   mounting plates in the rear wall. The touchscreen was mounted to an 82 cm aluminium panel

237   to offset it from the ground, with its height adjustable to the dog's height. An automatic feeder

238 was placed 2 m away from the touchscreen device (see Figure 1 for experimental setup). The

239 touchscreen utilizes capacitive sensing to monitor and record touches. The Opensesame 3.0.7

240 software was used for stimulus presentation and response recording, with a dedicated Windows

241 based PC for the testing room.
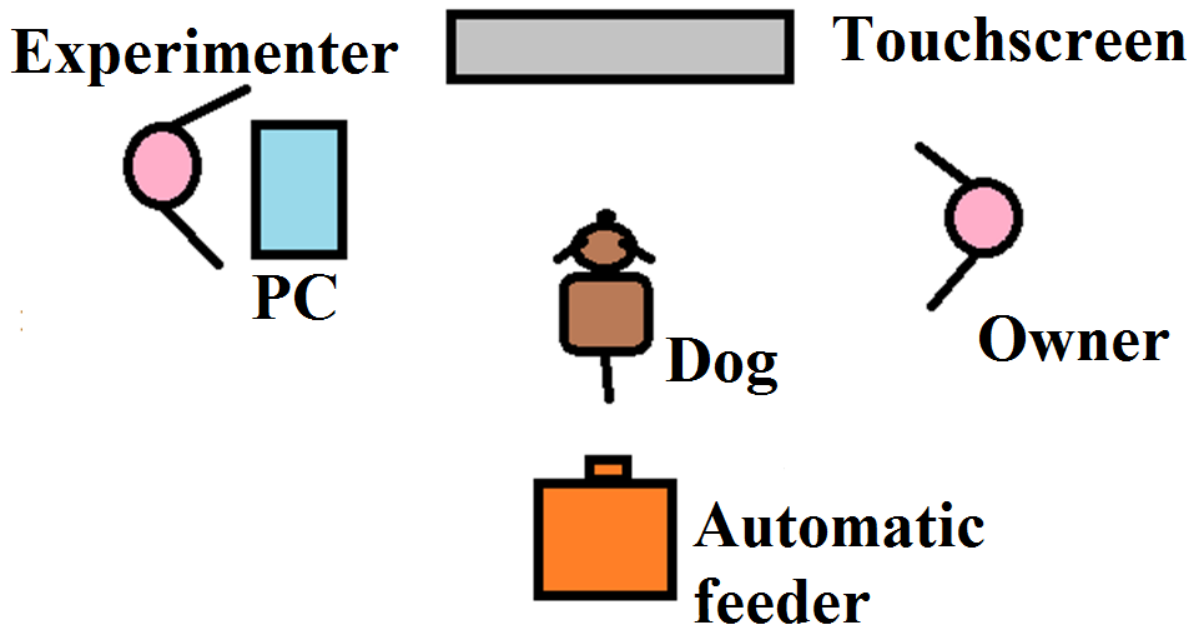
242

243 Figure 1. *Depiction of experimental setup showing location of experimenter, owner, dog,*
244 *touchscreen device, and automatic feeder.*
245

246 **Stimuli.** Experimental stimuli were blue and yellow circles and triangles (with overall

247 dimensions of 300 × 300 pixels). The colours blue and yellow were chosen because unlike

248 humans, who have cone cells in their retina that are sensitive to three different types of colours

249 (blue, green, and red), dogs have cone cells sensitive only to two colours (i.e., blue and yellow);

250 as such, it is easiest for dogs to differentiate blue and yellow based on colour (as opposed to

251 e.g., brightness) (Jacobs, Deegan, Crognale, & Fenwick, 1993).

252   An early comparison of stimuli groups (based on stimulus characteristics, i.e., colour and

253 shape) indicated that neither colour, nor shape, nor the interaction between the two had an

254 effect on dogs' performance (two-way ANOVA main and interaction effect $ps > .328$). Thus,

255 dogs were randomly assigned to one of two groups to control for stimulus characteristic (colour

256 or shape) effects. For example, for one group, a yellow circle was the "go" stimulus and a blue

257 triangle was the "no-go" stimulus whereas for another groups, a blue circle was the "go"

258 stimulus and a yellow triangle was the "no-go" stimulus.

259 *Training.* Training for the Go/No-Go test consisted of three phases generally consistent

260 with training for rodents (Levin & Buccafusco, 2006); during the first phase, which was a "go"

261 training phase, dogs were presented only with their respective "go" stimulus and trained to

262 respond to such stimulus by poking with or pressing their noses against it (hereafter: nose poke)

263 on the touchscreen. Dogs were rewarded with a treat (mostly dry dog food but in some cases,

264 when the dog had food allergies, a treat chosen by the owner was used, typically sausage) for

265 every correct "go" response. Dogs moved on to the second training phase after they completed

266 2 sets of 20 stimuli one after another with at least 80% accuracy. On average, dogs completed

267 the first phase in $M = 5.79$, $SE = 0.55$ sessions (range: 1-14).

268 During the second phase, which was a discrimination training phase, dogs were

269 simultaneously presented with their respective "go" and "no-go" stimuli and trained to respond

270 only to the "go" stimulus by executing a nose poke but not to the "no-go" stimulus. Dogs were

271 rewarded with a treat for every correct "go" response but received no feedback for omission

272 (not poking the "go" stimulus) or commission (poking the "no-go" stimulus) errors. Dogs

273 moved on to the third training phase after they completed 2 subsequent sets of 20 stimuli with

274 at least 80% accuracy. On average, dogs completed the second phase in $M = 4.17$, $SE = 0.34$

275 sessions (range: 2-8).

276 During the third and last phase, which was a "no-go" training phase, dogs were presented

277 either with their respective "go" stimulus or with their "no-go" stimulus (50% "go" and 50%

278 "no-go"). Stimuli were presented in a pseudo-random fashion, such that no more than two of

279 the same type was presented following one another and the first and the second stimuli could

280 not be the same. Regarding "go" stimuli, dogs continued to be rewarded for every correct "go"

281 response. Regarding "no-go" stimuli, dogs were rewarded for every correct "no-go" response,

282 with the time between the stimulus onset and reward gradually increased up to 3 s. As such,

283 consistent with other animal studies of go/no-go paradigms, dogs were rewarded with a treat

284 for every correct "go" *and* "no-go" response (e.g., Matsumoto, Suzuki, & Tanaka, 2003;

285 Tremblay & Schultz, 2000). Dogs moved on to the Go-No-Go test after they completed 2

286 subsequent sets of 20 stimuli with at least 80% accuracy. On average, dogs completed the third

287 phase in $M = 8.14$, $SE = 1.05$ sessions (range: 1-24).

288   ***Test.*** The Go/No-Go test consisted of 2 sets of 20 stimuli (60% "go" and 40% "no-go").

289 *Note.* During training phase, a 50-50 ratio was employed to ensure feasibility of dogs learning

290 the paradigm. While this 50-50 split was necessary for training purposes, it is generally not

291 considered appropriate in case of Go/No-Go tests, as an underlying assumption in such tests is

292 that one response is more automatic, i.e., prepotent and, as such, can be withheld only via

293 recruitment of inhibitory functions and processes. For one response to be more automatic and

294 prepotent, one stimulus, which is thus the "Go" stimulus, is presented more frequently than the

295 "No-Go" stimulus. Although there is variability across prior studies in terms of the portion of

296 "go" and "no-go" stimuli presented in Go/No-Go tests, in the current study, the 60-40 ratio was

297 chosen based on pertinent literature (e.g., Liu et al., 2015). A correct "go" response indicated

298 that the dog executed a nose poke within 3 s after stimulus onset and an omission error indicated

299 that the dog did not execute a nose poke within 3 s. A correct "no-go" response indicated that

300 the dog did not execute a nose poke within 3 s after stimulus onset and a commission error

301 indicated that the dog did execute a nose poke within 3 s (see Supplement for an illustrative

302 video clip of two dogs participating in the Go/No-Go test).

303   **Rating scale measures.** Dogs' owners were asked to complete questionnaires online

304 that was comprised of the following rating scales and questions.

305   ***IA and H/I.*** Individual differences in IA and H/I were measured using the *Dog-ADHD*

306   *Rating Scale* – Owner Version (Lit et al., 2010; Vas et al., 2007), which is a 13-item (6 items

307   measuring IA and 7 items measuring H/I) owner-report measure of dogs' level of attention and

308   hyperactivity/impulsivity. The measure was originally developed based on a well-validated and

309   widely used parent-report rating scale measure of ADHD and related problems in children, the

310   ADHD-RS-IV (DuPaul, 1998). Owners indicate the frequency with which their dog behaves

311   as described in each item (ranging from 'never' to 'very often'). Initial examination of the

312   measure's psychometric properties (with over 200 animals representing over 60 different dog

313   breeds) indicated preliminary evidence for its internal consistency and external validity (i.e.,

314   age-, sex-, and training-based differences given rating scale scores) (Vas et al., 2007). Greater

315   scores indicate greater difficulties with IA and H/I. In the current sample, the subscales

316   exhibited acceptable internal consistency, with Cronbach's alphas (α) ranging from .60 to .88

317   and so did the total scale $\alpha = .84$.

318   ***Covariates of interest.*** Individual differences in personality were measured using the

319   canine Big Five Personality Inventory (Gosling, Rentfrow, & Swann, 2003), which is a 43-

320   item owner-report measure of dogs' personality. The questionnaire was originally developed

321   based on the Big Five framework, an extensively researched and widely used model of

322   personality. Owners indicate the degree to which (ranging from 'not at all' to 'extremely') each

323   characteristic is true about their dog as described in each item. The measure has exhibited

324   acceptable psychometric properties as indexed by internal consistency (Turcsán, Range,

325   Virányi, Miklósi, & Kubinyi, 2012). In the current study, the five subscales, confidence (the

326   opposite of neuroticism), conscientiousness, cooperation (comparable to agreeableness on the

327   human Big Five), extraversion, and openness exhibited acceptable internal consistency (αs

328   ranging from .60 to .74), except for conscientiousness, which had unacceptable internal

329   consistency ($\alpha = .46$) and thus was not considered in the analyses.

330   ***Covariates of non-interest.*** Relevant covariates that have been previously hypothesized

331   or shown to be associated with differences in canine IA and H/I, were dogs' owner-reported

332   age, sex, and training status (Vas et al., 2007).

333   ***Ethical statement***

334   Owners volunteered to participate in the behavioural paradigms with their dogs and

335   completing the questionnaires and gave written consent. Non-invasive animal research is

336   currently allowed without need for permission from the University Institutional Animal Care

337   and Use Committee (UIACUC). A written statement (#PEI/001/3819-4/2015) was obtained

338   from the Food Chain Safety and Animal Health Directorate Government Office based on the

339   decision of the Scientific Ethic Council of Animal Experiments. According to this statement

340   and the corresponding definition by law, the current non-invasive observational study is not an

341   animal experiment.

342   ***Analytic Plan***

343   SPSS V22.0.0.0 was used for all analyses. Descriptive statistics were calculated to

344   characterize the sample on all dependent and independent variables as well as covariates.

345   Dependent variables of interest were omission error percent (the proportion of omission errors

346   relative to the total number of "go" stimuli), commission error percent (the proportion of

347   commission errors relative to the total number of "no-go" stimuli), average latency of correct

348   "go" responses (the time, in s, that has passed between stimulus onset and execution of a correct

349   "go" response), and average latency of commission errors (the time, in s, that has passed

350   between stimulus onset and execution of a commission error). Independent variables of interest

351   were dogs' IA and H/I scores. Covariates of interest were dogs' personality dimension scores

352   and co-variates of non-interest were age, sex, and training status.

353   To evaluate the effects of independent (IA and H/I) and covariate (personality, age, sex,

354   and training status) variables on omission and commission error percent, multiple multivariate

355   linear regression analyses (using the SPSS GLM-multivariate option) with backward

356   elimination were conducted, taking into consideration both significance level of individual

357   predictors and model fit. To evaluate the effects of independent and covariate variables on

358   latency of correct "go" and commission errors, survival analyses (i.e., Cox regression analysis

359   with occurrence of a response as terminal event) with backward elimination were conducted,

360   taking into consideration both significance level of individual predictors and model fit. Model

361   assumptions were considered prior to (or following, where appropriate) all analyses; these were

362   met. Results are reported for final set of individual predictors/models only.

363   A few considerations regarding the way in which results are reported and to be interpreted

364   are worthy of note. First, results are presented as an estimate of an effect size, followed by an

365   exact probability (a p value) and a 95% confidence interval (CI). Effect sizes indicate the

366   magnitude or size of the association observed whereas p values indicate whether an effect is

367   nil. CIs provide likely boundaries for the lower and upper limits of the true effect size in the

368   population. A 95% CI that begins (or ends) precisely at zero would yield a p value of .05 and

369   a 99% CI that begins (or ends) precisely at zero would yield a p value of .01. However, unlike

370   a p value which supports a dichotomous decision of whether there is an effect, the CI gives a

371   sense of both the precision of the estimate (the narrower, the more precise), as well as its

372   extremity (upper and lower limits).

373   In summary, following the estimation, i.e., effect size approach, we provide an index of

374   the effect size, followed by an exact probability and a 95% CI but do not make statements about

375   statistical significance[1].

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[1] When interpreting indices of effect size, guidelines regarding the magnitude of those are as follows: For multiple multivariate linear regression analyses, in case of η_p^2, a small effect ≤.02, medium ≤.13, and large effect ≤.26 (http://imaging.mrc-cbu.cam.ac.uk/statswiki/FAQ/effectSize). β coefficients (in SD units) can be compared to assess the relative strength of predictors, e.g., "1 SD decrease/increase in X would yield a β SD decrease/increase in Y". Some argue βs can be interpreted as weak ≤0.2, moderate between 0.2 and 0.5, strong if >0.5 (Acock, 2008; p.272). For cox regression analyses, χ^2 or the likelihood chi-square statistic is an index of overall model fit, calculated by comparing the deviance (-2*log likelihood) of the obtained model, with all predictors and covariates specified, against the model with all such variables dropped. In case of $\exp(\beta)$, a value >1, means that there is

376   The datasets generated and/or analysed during the current study are available from the

377   corresponding author upon reasonable request.

378   **Results**

379   **Descriptive statistics**

380   For data on individual dogs across variables of interest, see Tables 1 and 2. For

381   descriptive statistics, including *M, SE,* 95% confidence intervals (CI) and range, see Table 3.

Table 1

Data on Individual Dogs Across Demographic and Rating Scale Variables on the owner-report Dog-ADHD Rating Scale (Lit et al., 2010; Vas et al., 2007) and owner-report the Dog Personality Questionnaire (Jones, 2009).

Name	IA	HI	Ext	Coop	Conf	Open	Consc	Age	Sex	Training status
Akina	2	10	28	28	29	32	34	2	Female	Advanced
Alma	2	6	29	39	34	34	37	8	Female	Basic
Barkus	7	10	29	42	31	37	28	5	Male	Basic
Bingó	6	8	34	36	29	39	37	1	Male	Intermediate
Bogyó	5	3	18	40	34	30	33	3	Female	Intermediate
Borisz	5	9	30	39	31	38	29	5	Male	Basic
Demi	1	9	28	39	29	36	34	3	Female	Basic
Dolores	7	5	28	34	27	36	28	3	Female	Advanced
Döme	2	10	31	40	29	38	35	4	Male	Basic
Joker	5	8	27	28	21	35	33	2	Male	Advanced
Kitty	2	5	27	43	26	38	37	1	Female	None
Kópé	6	11	28	32	31	30	33	9	Male	Basic
Leia	6	4	27	36	23	33	36	4	Female	Intermediate
Lili	3	4	29	34	29	38	33	3	Female	Basic
Liza	4	14	33	31	22	39	35	4	Female	Advanced
Lizi	5	6	33	32	27	36	34	6	Female	Advanced
Lord	3	0	17	24	37	22	36	10	Male	None
Lucky	2	6	27	41	31	33	31	10	Male	Basic
Mara	6	11	32	38	23	38	33	2	Female	Advanced
Molly	3	6	35	42	24	34	33	4	Female	Intermediate
Monty	3	5	29	33	28	34	35	7	Male	None
Öre	7	16	36	30	34	34	33	2	Male	None
Pille	5	11	35	40	30	35	34	1	Female	None
Rozi	0	2	26	36	30	39	45	8	Female	Basic
Rynn	3	9	27	40	28	33	29	2	Female	Basic

greater probability of experiencing the terminal event and a value <1 means that an increase in one unit for that variable will decrease the probability of experiencing an end point throughout the observation period.

Simon	3	4	30	44	37	37	36	3	Male	None
Vackor	5	19	38	33	18	36	32	9	Male	None
Zajec	8	12	33	39	28	39	29	3	Female	Basic
Zebulon	7	9	34	34	30	33	30	9	Male	Basic

Note. Ext = Extraversion, Coop = Cooperation, Conf = Confidence, Open = Openness, Consc = Conscientiousness

382

Table 2

Data on Individual Dogs Across the canine Go/NoGo Behavioural Inhibition Test Performance Variables.

Name	Omission error percent	Commission error percent	Correct "go" latency (ms)	Commission error latency (ms)
Akina	4.17	37.50	895.26	1046.50
Alma	0.00	37.50	717.54	875.17
Barkus	12.50	37.50	877.43	848.00
Bingó	0.00	31.25	766.75	1123.80
Bogyó	12.50	18.75	1491.90	1659.67
Borisz	4.17	12.50	1608.35	2065.00
Demi	16.67	0.00	1574.70	3000.00
Dolores	0.00	0.00	1434.21	3000.00
Döme	33.33	12.50	753.38	1502.00
Joker	0.00	18.75	953.67	1739.00
Kitty	0.00	25.00	782.25	1313.25
Kópé	0.00	50.00	841.08	1354.63
Leia	29.17	6.25	2250.59	2804.00
Lili	16.67	6.25	1049.45	865.00
Liza	45.83	12.50	1251.23	538.50
Lizi	4.17	68.75	741.70	665.73
Lord	8.33	18.75	939.41	936.33
Lucky	0.00	12.50	1110.54	1101.00
Mara	0.00	0.00	1002.96	3000.00
Molly	8.33	31.25	926.86	788.00
Monty	25.00	6.25	1882.50	2416.00
Öre	12.50	56.25	1199.05	635.44
Pille	16.67	6.25	1218.00	2720.00
Rozi	4.17	0.00	1620.35	3000.00
Rynn	12.50	12.50	1179.38	1851.00
Simon	8.33	6.25	1001.86	1827.00
Vackor	15.00	60.00	1463.82	1376.67
Zajec	0.00	0.00	1016.25	3000.00
Zebulon	8.33	12.50	858.00	1154.00

383

Table 3

Descriptive Statistics on Study Variables

	range	min	max	*M* (95%CI)
Omission error %	45.83	.00	45.83	10.29 (6.58; 14.60)
Commission error %	68.75	.00	68.75	20.60 (13.79; 27.93)
Correct "go" latency (ms)	1533.05	717.54	2250.59	1152.02 (1022.36; 1294.52)
Commission error latency (ms)	2461.50	538.50	3000.00	1662.27 (1343.28; 1981.32)
IA	8	0	8	4.24 (3.52; 5.00)
HI	19	0	19	8.00 (6.62; 9.52)
Confidence	19	18	37	28.62 (27.04; 30.17)
Conscientiousness	17	28	45	33.52 (32.31; 34.83)
Cooperation	20	24	44	36.10 (34.24; 37.93)
Extraversion	21	17	38	29.59 (27.90; 31.07)
Openness	17	22	39	35.03 (33.69; 36.35)
Age	9	1	10	4.59 (3.59; 5.66)

Note. The conscientiousness subscale had acceptable but low internal consistency; all corresponding data should be interpreted with caution.

384

385 **Errors**

386   The omnibus model with H/I predicting omission and commission error percent was

387 significant, $F(2,26) = 3.38$, $p = .049$ ($\eta_p^2 = .21$; a large effect, Watson, 2016). This effect was

388 driven by greater H/I associated with greater commission error percent, $\beta = 1.72$, $p = .047$ (SE

389 $= 0.83$; 95% CIs [0.02; 3.42]) (Figure 2). Differences in H/I accounted for 14% of the variance

390 in the outcome ($\eta_p^2 = .14$; a medium-large effect).
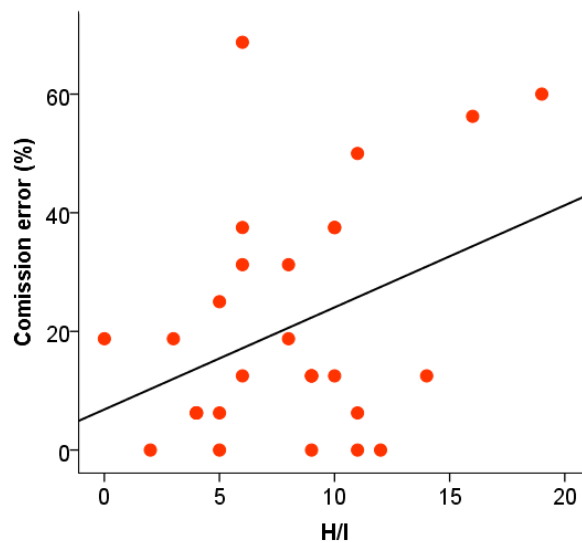
391

392 Figure 2. *Greater owner-rated H/I is associated with a greater proportion of commission*
393 *errors on the Go-No/Go task.*

Note. The fitted regression lines are default SPSS fitted lines representing the trend of the data,
395 with the slope corresponding to the unstandardized regression coefficient *b* of a linear
396 regression equation, where Y = *a* (i.e., intercept) + *b*X (in this case, y=6.83+1.72*x).
397
398 **Response times**

399 Training status, confidence, openness, and extraversion jointly predicted average

400 latency to correct "go" responses ($\chi^2(6) = 10.57$, $p = 0.103$). Dogs were *less likely* to have an

401 earlier correct "go" response if they had none compared to basic training ($\exp(\beta) = 0.12$, $p =$

402 0.012 [0.02; 0.62]) (but the intermediate to none or the advanced to none difference was not

403 significant) or had lower scores on openness ($\exp(\beta) = 0.83$, $p = 0.062$ [0.69; 1.01]). Dogs were

404 *more likely* to have an earlier correct "go" response if they were higher on: confidence ($\exp(\beta)$

405 $= 1.14$, $p = 0.061$ [0.99; 1.30]) or extraversion ($\exp(\beta) = 1.20$, $p = 0.013$ [1.04; 1.38]).

406 Training status, sex, confidence, openness, and extraversion jointly predicted average

407 latency to commission errors ($\chi^2(6) = 12.87$, $p = 0.065$). Dogs were *less likely* to have an earlier

408 commission error (i.e., poked) if they had none compared to basic training ($\exp(\beta) = 0.15$, $p =$

409 0.044 [0.02; 0.95]) (but the intermediate to none or the advanced to none difference was not

410 significant). Dogs were also *less likely* to have an earlier commission error if they had lower

411 scores on: openness ($\exp(\beta) = 0.75$, $p = 0.005$ [0.62; 0.92]) or on IA ($\exp(\beta) = 0.76$, $p = 0.049$

412 [0.58; 1.00]). Dogs were *more likely* to have an earlier commission error if they were female

413 ($\exp(\beta) = 2.96$, $p = 0.043$ [1.03; 8.51]) or had higher scores on confidence ($\exp(\beta) = 1.12$, $p =$

414 0.094 [0.98; 1.27]) or extraversion ($\exp(\beta) = 1.29$, $p = 0.005$ [1.08; 1.53]).

Discussion

416 We examined whether differences in dogs' behavioural inhibition indexed by performance on

417 a self-developed touchscreen Go/No-Go paradigm is related to differences in their owner-rated

418 inattention (IA) and hyperactivity/impulsivity (H/I) levels, accounting for relevant third

419 variables. Results indicated a unique association between H/I and commission errors (the

420 proportion of commission errors relative to the total number of "no-go" stimuli) as well as

421 associations between latency to correct "go" responses *and* to commission errors with training

422 status and personality. Results further indicated a relationship between latency to commission

423 errors and IA (shorter latency was related to greater IA).

424   Contrary to human data, IA was not related to error rate. However, consistent with such

425 data, H/I uniquely predicted commission error rate – evidence for convergent validity of the

426 behavioural paradigm and the rating scale. In addition, these findings are also evidence for

427 discriminant validity of the behavioural paradigm and the rating scale in dogs (albeit to a lesser

428 extent), as omission errors similarly correlate less with H/I and commission errors correlate

429 less with IA in humans (Bezdjian et al., 2009; Trommer et al., 1988).

430   Relative to no prior training, dogs with basic training responded faster, regardless of

431 accuracy (both correct "go" and commission errors). This effect did not hold when comparing

432 dogs with no prior training to dogs with any of the higher levels of training. An explanatory

433 hypothesis is that our sample was not large enough or that we did not have sufficiently fine-

434 grained distinctions between training levels to detect differences between no prior training and

435 the higher levels of training. Another potential explanation is that differences between no and

436 basic training may manifest in simpler behavioural differences, such as response speed, but

437 differences between no and more advanced training may manifest in higher-level skills, such

438 response speed *and* accuracy. Interestingly, in humans, athletes, relative to non-athletes (e.g.,

439 Chan, Wong, Liu, Yu, & Yan, 2011), exhibit faster response latencies and fewer commission

440 errors on Go/No-go tasks. The observed differences between no and basic training may be

441 comparable to those observed between non-athletes and athletes, with "basic training" being

442 comparable to sports, as argued by others (Helton, Feltovich, & Velkey, 2009).

443   Greater confidence and extraversion were associated with smaller latency to correct "go"

444 responses and commission errors, similar to training status, regardless of accuracy. Humans

445 scoring higher on neuroticism (opposite of confidence) do not exhibit differences in their

446   reaction time but exhibit greater variability in this regard across tasks and time (Robinson &

447   Tamir, 2005). Results parallel human data indicating extraversion is associated with faster

448   movement- and reaction time (Stahl & Rammsayer, 2007). Following these patterns, openness

449   was associated with greater latency to correct "go" responses and commission errors. Although

450   in humans there is a similar negative association between openness and reaction time

451   (Wainwright, Wright, Luciano, Geffen, & Martin, 2008), these associations are small and not

452   well-replicated (Graham & Lachman, 2012).

453   Interestingly, dogs were *more likely* to have an earlier commission error if they were

454   female. Data on relevant human sex differences are mixed: e.g., on an equiprobable auditory

455   Go/No-Go task, there was no difference between men and women in reaction times (Melynyte,

456   Ruksenas, & Griskova-Bulanova, 2017) whereas on a cognitive inhibition/interference control

457   task, men's responses were consistently slower (Mekarski, Cutmore, & Suboski, 1996).

458   Finally, IA was associated with latency to commission errors (i.e., lower IA was related

459   to greater latency to commission errors) but not to correct "go" responses and H/I was not

460   associated with either latency variables. These results are inconsistent with human findings

461   suggesting that youth with primary IA tend to respond more cautiously and slowly (including

462   in Go/No-Go tasks) whereas those with combined IA and H/I tend to have a hasty, impulsive

463   response style (Derefinko et al., 2008; Trommer et al., 1988; but see, for an exception Bezdjian

464   et al., 2009).

465   **Limitations and Future Directions**

466   These results will need replication, ultimately with larger samples. Additional aspects of

467   behavioural disinhibition beyond delay of gratification (Riemer et al., 2014; Wright et al.,

468   2012), such as action cancellation, should be examined. Modifications to rating scale measures

469   of dog ADHD-B/S may be necessary given acceptable but insufficiently stable psychometric

470   properties across samples (including barely acceptable internal consistency of the IA subscale

471 in the current sample and data obtained by Lit et al., 2010; Vas et al., 2007). While humans

472 receive little to no training prior to Go/No-Go measurements, dogs' training for the test may

473 have reduced errors and response times, potentially explaining null effects. A more difficult

474 canine Go/No-Go test may help address reduced variability. To ensure that dogs are not trained

475 in the same setting where they are tested – and thus increase human-dog comparability, an

476 automatic Go/No-Go test for the home environment may be developed. Inconsistences between

477 human and dog data may also reflect that some of the examined relations are not comparable

478 across humans and dogs. These alternative hypotheses will need disentangling, for better

479 understanding of the boundaries of the canine model of the relationship of human behavioural

480 inhibition and ADHD.

481   Nevertheless, rodent studies of behavioural inhibition and/or go/no-go performance

482 validate some biological or genetic modification, e.g., differences among mouse (Gubner,

483 Wilhelm, Phillips, & Mitchell, 2010; Majdak et al., 2016; Oakeshott et al., 2013) or rat strains

484 (Anker, Zlebnik, Gliddon, & Carroll, 2009) or as a result of lesions (Eagle, Baunez, et al., 2008)

485 using differences in task performance. Although fruitful in validating a model with regard to

486 associations between biological and behavioural aspects (i.e., predictive validity) (Sagvolden

487 et al., 2005), these tests do not demonstrate an expected convergence and divergence across

488 different indices of the behavioural phenotype, such as between differences in behavioural

489 inhibition and ADHD-B/S. Conversely, as noted, dogs naturally exhibit genetic

490 polymorphisms and individual differences relevant to inhibition and ADHD-B/S and we could

491 test and find support for evidence of convergent validity of behavioural inhibition and IA and

492 H/I in dogs. With this established, questions that cannot be addressed with rodents (e.g., due to

493 need for need for fluid and/or food restriction and restricted physical and social environment

494 not shared with humans) and a host of additional hypotheses can be tested with dogs, including

495 ones relevant to modelling functional impairment and treatment response in ADHD.

496   Our findings are in line with the growing body of work evincing the dog is an ideal animal

497   model of complex human processes, not only with regard to individual differences in

498   behavioral/neuropsychological (i.e., Go/No-Go performance reflecting behavioral inhibition)

499   and cognitive (e.g., ADHD-B/S)/temperamental or personality variables but also to the

500   *relationship* between those (e.g., H/I associated with commission errors). These results thus

501   suggest that the phenotypic variability in these characteristics in dogs is analogous to that

502   observed in humans, lending support to the dog's potential for ultimately modelling the

503   genotypic or biological variability that underlies this phenotypic variability in behavioral

504   inhibition or ADHD.

505   In summary, the current study is the first attempt at examining the relationship between

506   behavioural inhibition and individual differences in IA and H/I in domestic dogs. Our findings

507   add to the pertinent literature by extending the dog as an animal model of human behaviour

508   and cognition to behavioural inhibition and ADHD-like behaviours and symptoms.

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