J Neural Transm (2008) 115: 221–226
DOI 10.1007/s00702-007-0813-6
Printed in The Netherlands

Journal of Neural Transmission

Temporal reward discounting and ADHD: task and symptom specific effects

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Received 31 July 2007; Accepted 20 August 2007; Published online 19 September 2007

Summary. This study investigated a new aspect of the association between ADHD symptoms and delay aversion. Participants were 55 undergraduate Psychology students with varying levels of self-reported ADHD symptoms. Various delay aversion tasks were used, including real and hypothetical temporal discounting tasks previously used in the field of ADHD. ADHD symptoms, specifically hyperactivity/impulsivity, were associated with steep discounting, but only when rewards and delays were real. These data suggest that (1) real temporal discounting tasks are more sensitive to ADHD-related delay aversion than hypothetical ones; (2) delay aversion may be a causal mechanism specifically associated with ADHD-Combined and Hyperactive/Impulsive Types but not Inattentive Type. These findings may help refine behavioral treatment approaches and models of ADHD.

Keywords: Reward; delay discounting; temporal discounting; delay aversion; ADHD; impulsivity

Introduction

Temporal reward discounting (TD) refers to the observation that the subjective value of a reward decreases the longer one has to wait for it (Critchfield and Kollins 2001). As a result, people may forego larger monetary amounts in favor of smaller ones when the smaller amount is available sooner. Steeper TD, which reflects a greater tendency to discount the value of a reward due to its pre-reward delay, is often considered an index of impulsivity (e.g., Critchfield and Kollins 2001; Green and Myerson 2004). Indeed, numerous studies have demonstrated an association between impulsive behaviors and higher TD rates, including those involving student populations (Richards et al. 1999), pathological gamblers, and individuals with substance abuse and cigarette smokers (see Reynolds 2006 for review).

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Impulsivity is thought to play a key role in various psychiatric conditions such as substance abuse (Reynolds 2006), pathological gambling (Petry and Casarella 1999; Alessi and Petry 2003), and the common disorder attention-deficit/hyperactivity disorder (ADHD) (American Psychiatric Association 2000; Sonuga-Barke 2002). However, while many studies have examined the association between TD on the one hand and substance abuse or pathological gambling on the other (Reynolds 2006), it is only recently that researchers have started to study the link between TD and ADHD (Barkley et al. 2001; Scheres et al. 2006). Although the idea that ADHD is associated with weak preferences for larger delayed rewards is not new (Sonuga-Barke et al. 1992), the application of carefully designed TD paradigms to the study of ADHD is a recent development (Barkley et al. 2001; Scheres et al. 2006). Sonuga-Barke (1992) was the first to propose that children with ADHD are delay averse, expressed as an unusually strong preference for smaller immediate rewards over larger delayed ones. Earlier studies that tested this hypothesis have used single-choice paradigms such as the choice delay task (CDT), the Maudsley index of delay aversions (MIDA), or a Signal Detection Task (Sonuga-Barke 1992; Schweitzer and Sulzer-Azaroff 1995; Kuntsi et al. 2001; Solanto et al. 2001; Tripp and Alsop 2001; Antrop et al. 2006), and found evidence for this notion (see Luman et al. 2005 for a review). In the CDT, participants are presented with 20 choices between 1 point after 2 sec and 2 points after 30 sec, with 1 point being worth 5 cents. The MIDA is similar, except that points are exchangeable for a prize. Thus, in single-choice paradigms, neither magnitude of the immediate reward nor delay preceding the large reward is varied. While these paradigms have provided useful initial data in the study of delay aversion in ADHD, they do not allow for measuring the trade-off between reward magnitude and pre-reward delays, as TD paradigms do. This is an important shortcoming for the following reason: If the hypothesis is that individuals with ADHD are delay averse, their preference for smaller immediate rewards should increase with increasing delays to the large reward. Single-choice paradigms, however, cannot address this prediction.

By contrast, studies of impulsivity in adult populations have employed more sophisticated paradigms in which reward magnitude and delay duration are varied in order to obtain a temporal discounting function, which shows the decrease in subjective reward value as a function of increasing pre-reward delay (Green and Myerson 2004). Recently, researchers have started to take advantage of these paradigms and apply them to the study of ADHD (Barkley et al. 2001; Scheres et al. 2006). Barkley and colleagues used a TD task with hypothetical choices in adolescents with ADHD and healthy controls. Choices were between large rewards ($100 or $1000) delivered after delays up to 1 year and smaller immediate rewards. Adolescents with ADHD had stronger preferences for immediate rewards than controls in the $100 but not $1000 condition. Scheres et al. (2006) used a TD task with real choices. Children and adolescents with ADHD and healthy controls chose between 10 cents delivered after delays up to 30 sec and smaller immediate rewards. Although clear age effects were reported for TD (shallower TD with increasing age), no effect of diagnostic group was found.

Thus, the tasks that have been used to study delay aversion in ADHD vary greatly across studies. Although never stated explicitly, researchers assume that these tasks tap into the same underlying construct. However, it is an empirical question whether participants with ADHD are differentially sensitive to some of these measures. Therefore, this study aims at investigating how various delay aversion tasks correlate with ADHD symptoms. We also examined whether there is a unique association between the symptom domain impulsivity/hyperactivity and delay aversion. We used a real TD task with small rewards and short delays (Scheres et al. 2006), and a hypothetical TD task with large rewards and long delays (Barkley et al. 2001). In order to test whether hypothetical and real tasks correlate differently with ADHD symptoms while controlling for differences in reward magnitude and delay durations, we also administered the task with small rewards as a hypothetical task. Because of its common use in ADHD research, we also included the CDT.

Methods

Participants

Fifty-nine 18- and 19-year old undergraduate psychology students at the University of Arizona were enrolled in this study. Four were excluded from data analyses because of psychotropic medication use or due to technical problems. Therefore, we report data here for 55 participants (26 males, 29 females; mean age 18.2, *SD* 0.4).

Selection procedure and group characteristics

A large group of psychology undergraduate students from the University of Arizona completed the Conners' Adult ADHD Rating Scale (CAARS) self-report during an introductory Psychology course. Participants were selected based on their standardized score (T-score) on the CAARS DSM-IV ADHD Total Scale. More specifically, we selected and invited all participants who had T-scores above 65 (>93 percentile). For students with T-scores below 65, we included a portion from each range of T-scores so that the full range of 35–65 was covered. Nineteen participants (35%) had scores in the clinical range (>93 percentile). The remaining 36 participants had T-scores within the normal range, with number of participants evenly distributed across T-score ranges (Table 1).

Tasks

Participants performed the following computerized tasks: (1) a TD task with real, small rewards up to 10 cents, and real delays up to 60 sec; (2) a hypothetical version of task 1; (3) a hypothetical TD task with large rewards up to $100; (4) the CDT with repeated choices between 1 point after 2 sec and 2 points after 30 sec (Sonuga-Barke 1992; Solanto et al. 2001). Tasks were administered in 2 orders, balanced across participants: 1-4-3-2, and 3-2-4-1. Standardized task instructions were displayed on the screen. Left or right position of the delayed reward was balanced over trials, and trials were administered in the same pseudo-random order for all participants. Participants chose by pressing the key corresponding to the preferred option. Tasks started with 5 practice trials. After completion of the real TD task and the CDT, participants received the total amount of money won. The dependent variables were Area Under the discounting Curve (AUC) for all TD tasks, and proportion preference for the delayed reward for the CDT.

Temporal discounting task with small rewards – real version

Participants made repeated choices between a small variable reward (2, 4, 6, or 8 cents) delivered immediately (0 sec) and a large constant (10 cents)

Table 1. *Group characteristics for the Conners' Adult ADHD rating scale (CAARS) DSM-IV ADHD Total Scale*

T-score ranges on CAARS DSM-IV ADHD Total Scale	No. of participants		Mean T-score on CAARS DSM-IV ADHD Total Scale	
	No. of females	No. of males	Females	Males
35–45	2	7	39.0 (2.8)	37.8 (2.5)
46–55	7	8	51.0 (3.9)	51.1 (3.7)
56–65	9	3	60.1 (2.2)	61.0 (4.6)
66–90[a]	11	8	76.2 (8.1)	78.1 (10.4)

CAARS Conners' Adult ADHD Rating Scale.
[a] T-scores >65, corresponding to percentile >90 are typically considered to be in the clinical range, while T-scores <65 are considered to be in the normal range.

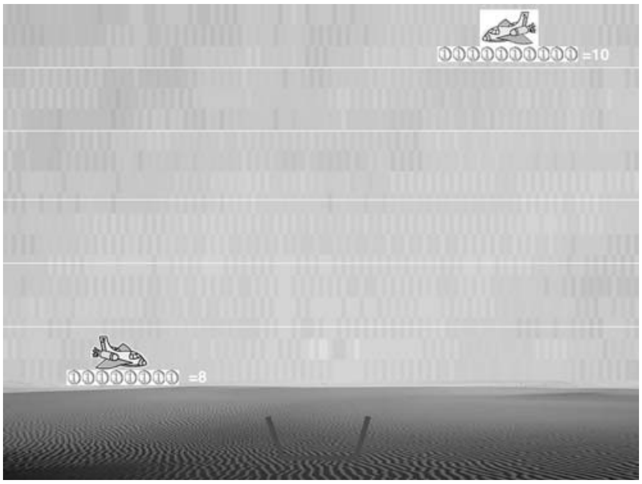

Fig. 1. Example of a trial on the temporal discounting task with real rewards and real delays. This choice is between 8 cents immediately and 10 cents after 60 sec

reward delivered after a variable delay of 5, 10, 20, 30, or 60 sec (modified from Scheres et al. 2006). Each small immediate reward was paired twice with every delay for the large reward, resulting in a total of 40 trials. Choices were represented by two airplanes on the screen, each carrying their corresponding quantity of money. Delays were represented by the "height" at which the planes were flying; the higher the plane, the longer the delay duration (see Fig. 1). Choosing the preferred plane resulted in the plane dropping its money cargo into the participant's basket on the screen, either immediately or after the appropriate delay. After each trial, the total amount won was updated on the screen.

Temporal discounting task with small rewards – hypothetical version

Choices were the same as in the real task (see above), except that this time, delays were not experienced and rewards were not paid. Choices were shown in white letters against a grey background.

Hypothetical temporal discounting tasks with large money amounts

Participants made choices between a small variable reward ($1, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, or 100) available today and a large constant reward ($100) available after a variable delay of 1 month, 1 year, 5 years, or 10 years (Barkley et al. 2001). Each small reward was paired twice with every delay for the large reward, resulting in a total of 96 trials. Choices were shown in white letters against a grey background.

Choice delay task

Participants made 20 repeated choices between 1 point (worth 5 cents) after 2 sec and 2 points after 30 sec (Solanto et al. 2001). Choices were represented by a green square labeled "1 point" and a blue square labeled "2 points". After choosing the preferred option, the screen turned green for 2 sec (immediate reward), or blue for 30 sec (delayed reward). After the delay, the corresponding number of points was posted on the screen, accompanied by a sound effect. Participants were informed of the number of trials they would play.

Procedure

Participants were invited by e-mail. After arrival, they read and signed a consent form before performing the tasks. The experimenter administered the tasks in one of two task orders. At the end of the session, participants received credit points for their time.

Data preprocessing

Data were preprocessed based on previously reported procedures (Myerson et al. 2001; Scheres et al. 2006). For each TD task subjective values were determined for the delayed reward for each delay (see Critchfield and Kollins 2001; Scheres et al. 2006) by two independent raters (AS and AL). Between-rater agreement of subjective values was very good (mean kappa 0.89, range 0.76–0.98). In rare cases of disagreement, a consensus on subjective value was reached by discussion. Area under the curve (AUC) was then calculated for the temporal discounting functions. In general, smaller AUCs reflect steeper discounting.

Missing data

One participant did not finish the hypothetical version of the 10 cents TD task. Thus, the total number of participants for this task was 54.

Statistical analyses

We computed correlations between inattention (mean of T-scores on CAARS Inattention scales A and E) and hyperactivity/impulsivity (mean of T-scores on CAARS Hyperactivity/Impulsivity scales B and F) on the one hand and the dependent measures on all tasks on the other.

In order to investigate the relative contribution of inattention and hyperactivity/impulsivity to delay aversion, we also performed regression analysis for each delay aversion task. In the first model, inattention was entered as a predictor at step 1, while hyperactiviy/impulsivity was entered at step 2. In the second model, the order was reversed. Thus, model 1 investigated the unique contribution of hyperactivity/impulsivity (over and beyond inattention) to variance in delay aversion tasks, while model 2 investigated whether inattention uniquely predicted variance in delay aversion tasks.

Results

Symptoms of inattention did not significantly correlate with choices on any of the tasks. Symptoms of hyperactivity/

Table 2. *Correlations between delay aversion task variables and ADHD symptoms*

	CDT proportion delayed chosen	TD real 10 cents AUC	TD hypothetical 10 cents AUC	TD hypothetical $100 AUC
ADHD hyperactive/ impulsive	−0.11	−0.28*	−0.07	−0.11
ADHD inattentive	−0.13	−0.15	−0.08	−0.07

CDT Choice delay task; *TD* temporal reward discounting; *AUC* Area under the discounting curve; *ADHD* attention-deficit/hyperactivity disorder.
* $p<0.05$; ** $p<0.01$.

Table 3. *Regression analyses measuring the unique contribution of hyperactivity/impulsivity symptoms (model 1) and inattention symptoms (model 2) to delay aversion task variables*

Dependent measures	Predictor			
	Model 1		Model 2	
	Step 1 inattention	Step 2 hyp/imp	Step 1 hyp/imp	Step 2 inattention
CDT proportion delayed chosen				
β	−0.13	−0.02	−0.02	−0.13
R^2	0.02	0.02	0.01	0.02
ΔR^2	0.02	0.00	0.01	0.01
TD real 10 cents AUC				
β	0.11	−0.37	−0.37	0.11
R^2	0.02	0.09	0.08	0.09
ΔR^2	0.02	0.07*	0.08*	0.01
TD hypothetical 10 cents AUC				
β	−0.09	0.00	0.00	−0.09
R^2	0.01	0.01	0.00	0.01
ΔR^2	0.01	0.00	0.00	0.00
TD hypothetical $100 AUC				
β	−0.02	−0.10	−0.10	−0.02
R^2	0.01	0.01	0.01	0.01
ΔR^2	0.01	0.00	0.01	0.00

hyp/imp Hyperactivity/impulsivity; *CDT* Choice delay task; *TD* temporal reward discounting; *AUC* Area under the discounting curve.
* $p < 0.05$.

impulsivity correlated significantly and negatively with AUC on the real TD task with 10 cents: higher levels of hyperactivity/impulsivity were associated with steeper discounting (see Table 2).

Regression analyses showed that symptoms of hyperactivity/impulsivity uniquely predicted temporal discounting rate on the real TD task, but not on any of the other tasks. Importantly, symptoms of inattention did not predict temporal discounting rate on the real TD task, after controlling for hyperactivity/impulsivity symptoms (see Table 3).

Discussion

This study investigated the association between ADHD symptoms (hyperactivity/impulsivity and inattention) and various delay aversion tasks. We found that ADHD symptoms, specifically hyperactivity/impulsivity, were correlated with TD, but only when rewards and delays were real.

The association between ADHD symptoms and steep TD is consistent with recent theoretical models of ADHD (Castellanos and Tannock 2002; Sagvolden et al. 2005; Sonuga-Barke 2002, 2005). The specificity of this finding for hyperactivity/impulsivity is intuitive, because steep TD is an operationalization of impulsivity, but not inattention (e.g., Barkley 1997). However, it is a new observation; previous studies have not examined the unique association between the two ADHD symptom domains and delay aversion. Moreover, this new finding was not predicted by current theoretical models of ADHD. For example, according to Sonuga-Barke (2005), ‘‘the emergence of delay aversion over time is hypothesized to lead to an elaboration of symptoms from impulsiveness to inattention and overactivity’’. The current data, however, suggest that delay aversion only contributes to symptoms of hyperactivity/impulsivity but not inattention. This finding also fits with recent functional brain imaging study in ADHD (Scheres et al. 2007) demonstrating that a reduction in ventral striatum activation during reward anticipation was specifically related to hyperactivity/impulsivity, but unrelated to inattention.

One previous study has used the real TD task with 10 cents in an ADHD population (Scheres et al. 2006). In that study, the task was administered to children and adolescents with ADHD (all subtypes were included) and healthy controls, and no significant group difference was found. Given the specificity between hyperactive/impulsive symptoms and delay aversion in the current study, it may be the case that a similar unique association was obscured in the 2006 study due to inclusion of the inattentive-type.

The finding that hyperactivity/impulsivity is associated with steep TD in the real task but not in either any of the hypothetical tasks or in the CDT suggests that an inability/unwillingness to delay gratification in relation to hyperactivity/impulsivity may mainly be present when delays are experienced and real money is at stake. It may also imply that impulsivity is associated with an inability/unwillingness to wait for larger rewards (as demonstrated by the significant association between hyperactivity/impulsivity and TD on the real task) while being unaware of such a choice style (as demonstrated by no association between hyperactivity/impulsivity and TD on the hypothetical task). To address this possibility, we computed correlations between hyperactivity/impulsivity and difference in scores between AUCs on the hypothetical and real TD tasks with 10 cents. We indeed found a significant correlation ($r = 0.26$, $p < 0.05$), indicating that participants with high levels of impulsivity thought they would be more patient than they actually were. This observation fits with recent work that demonstrated inflated self-perceptions in patients with ADHD, especially in domains of greatest deficits (Hoza et al. 2004).

The lack of association between ADHD symptoms and proportion preference for the large delayed reward on the CDT is inconsistent with previous child ADHD research in which relatively weak preferences for large delayed rewards were found in ADHD on single-choice tasks (Antrop et al. 2006; Kuntsi et al. 2001; Schweitzer and Sulzer-Alzaroff 1995; Sonuga-Barke 1992; Solanto et al. 2001). While some studies have raised the possibility of ceiling effects in the CDT in adolescents and adults (Bitsakou et al. 2006; Müller et al. 2006), no evidence for such an effect was found in our data (average proportion preference for large delayed reward 0.56, $SD = 0.40$, range 0–1). A more likely explanation may be that, despite the significant proportion of participants with ADHD symptoms in the clinical range, the current sample was most likely well-functioning. We may expect less (severe) deficits associated with hyperactivity/impulsivity in a group of unimpaired students than in clinically diagnosed patients with ADHD. The real 10 cents task (using secondary rewards) may have tempted participants more to choose the immediate reward than the CDT which used points exchangeable for money (tertiary rewards), and may thus be the most sensitive measure. A similar argument regarding the sample characteristics may be considered with respect to the lack of association between ADHD symptoms and TD on the hypothetical $100 tasks, despite a previous report of steep TD on this task in clinically diagnosed adolescents with ADHD (Barkley et al. 2001).

In conclusion, the current study showed that there is a unique relation between ADHD symptoms and real TD, suggesting that real TD tasks are more sensitive to ADHD-related delay aversion than hypothetical tasks. Moreover, the specific relation between TD and hyperactivity/impulsivity suggests that aberrant reward processing may be a causal mechanism specifically associated with ADHD-combined and hyperactive/impulsive types but not inattentive type. This is a new finding that fits with recent functional brain imaging research on reward processing and ADHD, and that can help to better tune behavioral treatment approaches and refine models of delay aversion and ADHD.

Acknowledgements

We gratefully acknowledge all participants. We thank Tiffany Glant for her help with data collection.

References

Alessi SM, Petry NM (2003) Pathological gambling severity is associated with impulsivity in a delay discounting procedure. Behav Processes 64: 345–354

American Psychiatric Association (2000) Diagnostic and statistical manual of mental disorders, 4th edn, text revision. American Psychiatric Association, Washington, DC

Antrop I, Stock P, Verte S, Wiersema JR, Baeyens D, Roeyers H (2006) ADHD and delay aversion: the influence of non-temporal stimulation on choice for delayed rewards. J Child Psychol Psychiatry 47: 1152–1158

Barkley RA (1997) Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. Psychol Bull 121: 65–94

Barkley RA, Edwards G, Laneri M, Fletcher K, Metevia L (2001) Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit/hyperactivity disorder (AD/HD) and oppositional defiant disorder (ODD). J Abnorm Child Psychol 29: 541–546

Bitsakou P, Antrop I, Wiersema JR, Sonuga-Barke EJ (2006) Probing the limits of delay intolerance: preliminary young adult data from the delay frustration task (DeFT). J Neurosci Method 151: 38–44

Castellanos FX, Tannock R (2002) Neuroscience of attention deficit/hyperactivity disorder: the search for endophenotypes. Nat Rev Neurosci 3: 617–628

Critchfield TS, Kollins SH (2001) Temporal discounting: Basic research and the analysis of socially important behavior. J Appl Behav Anal 34: 101–122

Green L, Myerson J (2004) A discounting framework for choice with delayed and probabilistic rewards. Psychol Bull 130: 769–792

Hoza B, Gerdes AC, Hinshaw SP, Arnold LE, Pelham WE, Molina BS, Abikoff HB, Epstein JN, Greenhill LL, Hechtman L, Odbert C, Swanson JM, Wigal T (2004) Self-perceptions of competence in children with ADHD and comparison children. J Consult Clin Psychol 72: 382–391

Kuntsi J, Oosterlaan J, Stevenson J (2001) Psychological mechanisms in hyperactivity. I. Response inhibition deficit, working memory impairment, delay aversion, or something else? J Child Psychol Psychiatry 42: 199–210

Luman M, Oosterlaan J, Sergeant JA (2005) The impact of reinforcement contingencies on AD/HD: a review and theoretical appraisal. Clin Psychol Rev 25: 183–213

Müller UC, Sonuga-Barke EJ, Brandeis D, Steinhausen HC (2006) Online measurement of motivational processes: introducing the Continuous Delay Aversion Test (ConDAT). J Neurosci Methods 151: 45–51

Myerson J, Green L, Warusawitharana M (2001) Area under the curve as a measure of discounting. J Expl Anal Behav 76: 235–243

Petry NM, Casarella T (1999) Excessive discounting of delayed rewards in substance abusers with gambling problems. Drug Alcohol Depend 56: 25–32

Reynolds, B. (2006). A review of delay-discounting research with humans: relations to drug use and gambling. Behav Pharmacol, 17: 651–667

Richards JB, Zhang L, Mitchell SH, De Witt H (1999) Delay or probability discounting in a model of impulsive behavior: effect on alcohol. J Exp Anal Behav 71: 121–143

Sagvolden T, Johansen EB, Aase H, Russel VA (2005) A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. Behav Brain Sci 28: 397–468

Scheres A, Dijkstra M, Ainslie E, Balkan J, Reynolds B, Sonuga-Barke E, Castellanos FX (2006) Temporal and probabilistic discounting of rewards in children and adolescents: Effects of age and ADHD symptoms. Neuropsychologia 44: 2092–2103

Scheres A, Milham MP, Knutson B, Castellanos FX (2007) Ventral striatal hyporesponsiveness during reward anticipation in attention-deficit/hyperactivity disorder. Biol Psychiatry 61: 720–724

Schweitzer JB, Sulzer-Azaroff B (1995) Self-control in boys with attention deficit hyperactivity disorder: effects of added stimulation and time. J Child Psychol Psychiatry 36: 671–686

Solanto MV, Abikoff H, Sonuga-Barke E, Schachar R, Logan GD, Wigal T, Hechtman L, Hinshaw S, Turkel E (2001) The ecological validity of delay aversion and response inhibition as measures of impulsivity in AD/HD: a supplement to the NIMH multimodal treatment study of AD/HD. J Abnorm Child Psychol 29: 215–228

Sonuga-Barke EJ (2005) Causal models of attention-deficit/hyperactivity disorder: from common simple deficits to multiple developmental pathways. Biol Psychiatry 57: 1231–1238

Sonuga-Barke EJS (2002) Psychological heterogeneity in AD/HD-a dual pathway model of behavior and cognition. Behav Brain Res 130: 29–36

Sonuga-Barke EJS, Taylor E, Sembi S, Smith J (1992) Hyperactivity and delay aversion-I. The effect of delay on choice. J Child Psychol Psychiatry 33: 387–398

Tripp G, Alsop B (2001) Sensitivity to reward delay in children with attention deficit hyperactivity disorder (ADHD). J Child Psychol Psychiatry 42: 691–698