



## University of Canberra

This thesis is available in print format from the University of Canberra Library.

**If you are the author** of this thesis and wish to have the whole thesis loaded here, please contact the University of Canberra Library at *e-theses@canberra.edu.au* Your thesis will then be available on the www providing greater access.

# The Accuracy of Time-to-Contact Estimation in the Prediction Motion Paradigm

Jiantao Pei, B. Ed., M. Sc.

A thesis submitted for the degree of  
Doctor of Philosophy  
of the University of Canberra.

Centre for Applied Psychology, University of Canberra, Australia.  
May 2002

## Acknowledgements

My appreciation is extended to those individuals who helped me and made my six-year Ph.D study an enjoyable learning experience in my professional endeavours.

It was with the great support and professional advice from my supervisor, Dr Michael Cook of the Australian National University, that I could achieve the completion of this thesis. His encouragement and patience throughout all the stages of my Ph.D study extended well beyond the bounds of a conventional Ph.D student/supervisor relationship. Also, I would like to thank my second supervisor, Prof. Marie Carroll (Pro Vice Chancellor of the University of Canberra), for her enthusiastic interest and support to this research. Thanks are extended to Prof. William H. Warren, Jr. of Brown University for providing the software used in their study and Mr Hugh Fisher of the Australian National University for his assistance on software programming.

Thanks are also extended to the Principal Research Psychologist Dr Allan Twomey and MAJ Damian O'Keefe of the Psychology Research and Technology Group at the Australian Department of Defence for their support of my Ph.D study and the approval of my application for study leave.

I am also grateful to the NRMA-ACT Road Safety Trust for offering me a generous scholarship to support my Ph.D study. Finally, I thank my parents for their encouragement and unwavering support over the course of my education. I very much look forward to spending more time with them after completion of my Ph.D study.

## Abstract

This thesis is concerned with the accuracy of our estimation of time to make contact with an approaching object as measured by the “Prediction Motion” (PM) technique. The PM task has commonly been used to measure the ability to judge time to contact (TTC). In a PM task, the observer’s view of the target is occluded for some period leading up to the moment of impact. The length of the occlusion period is varied and the observer signals the moment of impact by pressing a response key. The interval separating the moment of occlusion and the response is interpreted as the observer’s estimate of TTC made at the moment of occlusion. This technique commonly produces large variability and systematic underestimation. The possibility that this reflects genuine perceptual errors has been discounted by most writers, since this seems inconsistent with the accuracy of interceptive actions in real life. Instead, the poor performance in the PM task has been attributed to problems with the PM technique. Several hypotheses have been proposed to explain the poor PM performance. The *motion extrapolation hypothesis* asserts that some form of mental representation of the occluded part of the trajectory is used to time the PM response; the errors in PM performance are attributed to errors in reconstructing the target motion. The *clocking hypothesis* assumes that the TTC is accurately perceived at the moment of occlusion and that errors arise in delaying the response for the required period. The *fear-of-collision hypothesis* proposes that the underestimation seen in the PM tasks reflects a precautionary tendency to anticipate the estimated moment of contact. This thesis explores the causes of the errors in PM measurements.

Experiments 1 and 2 assessed the PM performance using a range of motion scenarios involving various patterns of movement of the target, the observer, or both. The

possible contribution of clocking errors to the PM performance was assessed by a novel procedure designed to measure errors in the wait-and-respond component of the PM procedure. In both experiments, this procedure yielded a pattern of systematic underestimation and high variability similar to that in the TTC estimation task. Experiment 1 found a small effect of motion scenario on TTC estimation. However, this was not evident in Experiment 2.

The collision event simulated in Experiment 2 did not involve a solid collision. The target was simply a rectangular frame marked on a tunnel wall. At the moment of “contact”, the observers passed “through” the target without collision. However, there was still systematic underestimation of TTC and there was little difference between the estimates obtained in Experiments 1 and 2. Overall, the results of Experiments 1 and 2 were seen as inconsistent with either the motion extrapolation hypothesis or the fear-of-collision hypothesis. It was concluded that observers extracted an estimate of the TTC based on optic TTC information at a point prior to the moment of collision, and used a timing process to count down to the moment of response. The PM errors were attributed to failure in this timing process. The results of these experiments were seen as implying an accurate perception of TTC.

It was considered possible that in Experiments 1 and 2 observers based their TTC judgements on either the retinal size or the expansion rate of the target rather than TTC. Experiments 3 and 4 therefore investigated estimation of TTC using a range of simulated target velocities and sizes. TTC estimates were unaffected by the resulting variation in expansion rate and size, indicating that TTC, rather than retinal size or image expansion rate per se, was used to time the observers' response.

The accurate TTC estimation found in Experiments 1-4 indicates that the TTC processing is very robust across a range of stimulus conditions. Experiment 5 further explored this robustness by requiring estimation of TTC with an approaching target which rotated in the frontoparallel plane. It was shown that moderate but not fast rates of target rotation induced an overestimation of TTC. However, observers were able to discriminate between TTCs for all rates of rotation. This shows that the extraction of TTC information is sensitive to perturbation of the local motion of the target border, but it implies that, in spite of these perturbations, the mechanism is flexible enough to pick up the optic TTC information provided by the looming of the retinal motion envelop of the rotating stimulus.

# Table of Contents

<b>Abstract</b> .....	<b>i</b>
<b>Acknowledgements</b> .....	<b>iv</b>
<b>List of Tables</b> .....	<b>x</b>
<b>Chapter 1. Time to contact</b> .....	<b>1</b>
<i>1.1 The problem of time to contact</i> .....	1
1.1.1 The terms related to “time to contact”.....	2
1.1.2 Perceiving and utilising TTC information.....	4
<i>1.2 Contemporary approaches to the visual mechanism of estimating TTC</i> .....	6
1.2.1 The indirect computation route.....	7
1.2.2 The direct perception route .....	9
<i>1.3 Outline of this thesis</i> .....	10
<b>Chapter 2. Possible Bases for Direct Perception of TTC Information</b> .....	<b>13</b>
2.1 <i>Tau theory</i> .....	14
2.2 <i>A taxonomy of tau</i> .....	20
2.3 <i>A possible role for high-order derivatives of optic flow</i> .....	23
2.4 <i>The neural basis of TTC processing</i> .....	23
2.5 <i>Modification of the tau hypothesis</i> .....	25
<b>Chapter 3. Research Methodology in TTC studies</b> .....	<b>29</b>
3.1 <i>Interceptive Action (IA) tasks</i> .....	30
3.2 <i>The Prediction Motion (PM) task</i> .....	33
3.2.1 The definition of the PM task.....	33
3.2.2 The features of a PM task.....	36
3.2.3 Response errors related to components in a PM task.....	38
3.3 <i>The Order of Arrival Judgement (OA) task</i> .....	40
3.4 <i>Summary: Relationship between the IA, OA and PM tasks</i> .....	42
3.4.1 Comparison between the IA, OA and PM tasks.....	42
3.4.2 Comments on hybrid methodologies.....	43
<b>Chapter 4. The accuracy of TTC estimation: a review of the research findings</b> .....	<b>47</b>
4.1 <i>Interceptive Action (IA) tasks</i> .....	48
4.2 <i>The Order of Arrival (OA) task</i> .....	54
4.2.1 The accuracy of the OA task.....	54
4.2.2 Factors influencing the accuracy of OA performance.....	56
4.2.2.1 <i>Retinal eccentricity</i> .....	56
4.2.2.2 <i>The effect of relative motion</i> .....	56
4.2.2.3 <i>Pictorial size</i> .....	57
4.2.2.4 <i>Other factors</i> .....	58
4.3 <i>The Prediction Motion (PM) task</i> .....	59
4.3.1 The accuracy of the PM task.....	59
4.3.2 Factors Influencing the Accuracy of PM performance .....	61
4.3.2.1 <i>Internal factors contributing to the accuracy of PM tasks</i> .....	61

4.3.2.2 External factors contributing to accuracy of a PM task .....	63
4.4 A caveat: the effects of extraneous variables and the direct perception approach in the PM task .....	77
<b>Chapter 5. Introduction to the Study .....</b>	<b>81</b>
5.1 Clocking errors .....	83
5.2 The measurement of clocking errors .....	85
5.3 Motion extrapolation errors .....	91
5.4 Other factors contributing to the PM errors .....	96
5.4.1 Tendency to avoid risk .....	97
5.4.2 Memory .....	98
5.5 Explanations of the errors in PM performance .....	98
5.6 The indirect computation route .....	102
5.7 The stimuli in the study .....	105
5.8 Summary of the study .....	107
<b>Chapter 6. Experiment 1. The accuracy of TTC estimation: travel on a patterned     ground surface under various motion scenarios .....</b>	<b>114</b>
6.1 Introduction .....	114
6.1.1 Measurement of the clocking errors in PM performance .....	115
6.1.2 The choice of motion scenario .....	119
6.1.3 Predictions .....	125
6.2 Method .....	128
6.2.1 PM test .....	128
6.2.2 TI test .....	128
6.2.3 Participants .....	128
6.2.4 Apparatus .....	129
6.2.5 Software .....	129
6.2.6 Display in the PM study .....	129
6.2.7 Procedure .....	131
6.3 Results .....	133
6.3.1 Performance on the PM tasks .....	133
6.3.2 Performance in the TI task .....	136
6.4 Discussion .....	138
6.4.1 The similarity of error patterns of the TI and PM performance .....	138
6.4.2 The accuracy of TTC perception .....	140
6.4.3 The TTC estimates were based on TTC cues .....	143
6.4.4 The effect of motion scenario .....	144
<b>Chapter 7. Experiment 2. The accuracy of TTC estimation: travel in a tunnel     under various motion scenarios .....</b>	<b>149</b>
7.1 Purpose and rationale .....	149
7.2 Method .....	150
7.2.1 Participants .....	151
7.2.2 Software .....	151
7.2.3 Display in the PM study .....	151
7.2.4 Procedure .....	153
7.3 Results .....	154
7.3.1 Performance on the PM tasks .....	154
7.3.2 Performance on the TI tasks .....	158
7.4 Discussion .....	159



7.4.1 The fear-of-collision hypothesis.....	159
7.4.2 The accuracy of TTC perception.....	161
7.4.3 Basis of the PM performance.....	165
<b>Chapter 8. Experiment 3. Stimulus variables affecting TTC estimation: the effect of speed .....</b>	<b>167</b>
8.1 Purpose and rationale.....	167
8.2 Method.....	169
8.2.1 Observers .....	169
8.2.2 Procedure .....	169
8.3 Results .....	170
8.4 Discussion .....	172
8.4.1 Absence of a speed effect.....	172
8.4.2 Disagreement with previous studies.....	173
8.4.3 Other confounding variables.....	174
<b>Chapter 9. Experiments 4 and 5. Stimulus variables affecting TTC estimation: the effects of target size and target rotation.....</b>	<b>177</b>
9.1 Experiment 4: The effect of target size.....	178
9.1.1 Method.....	180
9.1.2 Results.....	181
9.1.3 Discussion.....	183
9.1.3.1 Absence of a size effect.....	183
9.1.3.2 Disagreements with previous studies.....	184
9.2 Experiment 5: The effect of rotation.....	185
9.2.1 Method.....	187
9.2.2 Results.....	189
9.2.3 Discussion.....	192
9.2.3.1 The ability to filter out rotation components of the optical information.....	196
9.2.3.2 Implications of the results of Experiment 5.....	199
<b>Chapter 10. General Discussion.....</b>	<b>201</b>
10.1 Summary of findings.....	201
10.2 Theoretical issues addressed in the study.....	203
10.2.1 The basis of errors in PM performance.....	203
10.2.2 Validity of the TI task.....	207
10.2.3 The accuracy of TTC perception.....	209
10.2.4 The nature of the perceptual process in TTC judgement.....	211
10.2.5 The robustness of the TTC mechanism.....	213
10.2.6 Summary of conclusions.....	214
10.3 Implications of this study.....	215
10.3.1 TTC processing underlying the PM performance.....	216
10.3.2 The PM and IA tasks involve similar perceptual processing of TTC information.....	219
10.4 Limitations of this study.....	220
<b>References .....</b>	<b>222</b>
<b>Appendix A: Results of Experiment 1 .....</b>	<b>230</b>
<b>Appendix B: Results of Experiment 2 .....</b>	<b>233</b>
<b>Appendix C: Results of Experiment 3 .....</b>	<b>236</b>

<b>Appendix D: Results of Experiment 4 .....</b>	<b>237</b>
<b>Appendix E: Results of Experiment 5 .....</b>	<b>239</b>
<b>Appendix F: Results of Pair-wise Comparison of TTC Estimates.....</b>	<b>242</b>
<b>Appendix G: Participant Consent Form.....</b>	<b>245</b>
<b>Appendix H: Related Publications.....</b>	<b>246</b>

## List of Figures

<b>Figure 2.1</b> The optic flow induced by observer's self-motion. ....	15
<b>Figure 2.2</b> The relation between target image and retinal image. After Lee (1980).....	16
<b>Figure 3.1</b> Schematic description of the action of catching a ball (with reference to Whiting & Sharp, 1974).....	31
<b>Figure 3.2</b> Schematic description of a PM task (after Whiting & Sharp, 1974).....	34
<b>Figure 3.3</b> The components of a PM task.....	37
<b>Figure 6.1</b> The parallels between the TI and PM tasks. ....	117
<b>Figure 6.2</b> The apparatus and display from Experiment 1: a schematic view of the equipment (above) and a sample display of Scenarios 2 to 6 (bottom). ....	130
<b>Figure 6.3</b> Group mean values of the mean of TTC estimates for different scenarios. ....	134
<b>Figure 6.4</b> Group mean values of the <i>SD</i> of TTC estimates for different scenarios. ....	134
<b>Figure 6.5</b> Group mean values of the mean of TTC estimates. ....	135
<b>Figure 6.6</b> Group mean values of the <i>SD</i> of TTC estimates. ....	136
<b>Figure 6.7</b> Group mean values of the mean of TI estimates. ....	137
<b>Figure 6.8</b> Group mean values of the <i>SD</i> of TI estimates.....	137
<b>Figure 6.9</b> The corrected mean of TTC errors as a function of actual TTC values. ....	140
<b>Figure 6.10</b> The corrected standard deviation of TTC estimates as a function of actual TTC values.....	141
<b>Figure 6.11</b> The corrected mean of TTC errors under various motion scenarios. ....	144
<b>Figure 6.12</b> The corrected standard deviation of TTC estimates under various motion scenarios. ....	145
<b>Figure 7.1</b> The display of tunnel configuration in Experiment 2. ....	152
<b>Figure 7.2</b> Group mean values of the mean of TTC estimates across different scenarios.....	155
<b>Figure 7.3</b> Group mean values of the <i>SD</i> of TTC estimates across different scenarios. ....	155
<b>Figure 7.4</b> Group mean values of the mean of TTC estimates. ....	156
<b>Figure 7.5</b> Group mean values of the <i>SD</i> of TTC estimates. ....	157
<b>Figure 7.6</b> Group mean values of the mean of TI estimates.....	158
<b>Figure 7.7</b> Group mean values of the <i>SD</i> of TI estimates.....	158
<b>Figure 7.8</b> The corrected mean of TTC errors as a function of actual TTC values. ....	162
<b>Figure 7.9</b> The corrected standard deviation of TTC estimates as a function of actual TTC values.....	163
<b>Figure 8.1</b> Mean of TTC estimates as a function of actual TTC for various speeds .....171	171
<b>Figure 8.2</b> Variability of TTC estimates as a function of actual TTC for various speeds .....171	171
<b>Figure 9.1</b> Mean of TTC estimates as a function of actual TTC for different sizes. ....181	181
<b>Figure 9.2</b> Variability of TTC estimates as a function of actual TTC for different sizes .....182	182
<b>Figure 9.3</b> Mean of TTC estimates as a function of actual TTC across various rotation speeds.....	189
<b>Figure 9.4</b> Variability of TTC estimates as a function of actual TTC across various rotation speeds.....	190
<b>Figure 9.5</b> Group mean values of the mean of TI estimates.....	191
<b>Figure 9.6</b> Group mean values of the <i>SD</i> of TI estimates.....	192
<b>Figure 9.7</b> The corrected mean of TTC errors as a function of actual TTC values. ....193	193
<b>Figure 9.8</b> The corrected standard deviation of TTC estimates as a function of actual TTC values.....	193
<b>Figure 9.9</b> The corrected mean of TTC errors across different rotation speeds. ....194	194
<b>Figure 9.10</b> The corrected standard deviation of TTC estimates across different rotation speeds.....	194

## List of Tables

<b>Table 2.1</b>	The possible direct cues to TTC estimation .....	14
<b>Table 2.2</b>	Taxonomy work of local tau and global tau (Tresilian, 1991) .....	21
<b>Table 3.1</b>	Comparison between the IA, PM and OA Tasks (Tresilian, 1995a, p. 237) .....	42
<b>Table 6.1</b>	Description of motion scenarios used in Experiment 1 .....	121
<b>Table 6.2</b>	Predicted order of difficulty of PM tasks with different motion scenarios.....	125
<b>Table 6.3</b>	The trial blocks across actual TTCs (ms) and motion scenarios .....	131
<b>Table 6.4</b>	The correlation between the slopes of the function relating estimated and actual TTCs and the slope for estimated and actual SOAs.....	139
<b>Table 8.1</b>	Viewing times and final distances for the various conditions in Experiment 3.....	175