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Samenvatting

Hoe kunnen we data verkregen uit psychologische experimenten het beste beschrijven? In dit proefschrift stelde ik dat dit bij uitstek gedaan kan worden met behulp van formele wiskundige modellen. Het doel van modelleren is om datapatronen te ontdekken en deze te beschrijven aan de hand van parameters die verschillende statistische of psychologische processen vertegenwoordigen. Er bestaan veel verschillende typen wiskundige modellen waarvan velen in dit proefschrift aan de orde zijn komen: Ik heb me gericht op beschrijvende en procesmodellen voor eenvoudige tweekeuze-responstijdtaken, modellen voor responsinhibitie zoals gemeten in het stopsignaalparadigma, multinomiale *processing-tree*-modellen voor de analyse van categorische data, en bekende statistische modellen zoals de t-toets, de variantieanalyse, correlaties en partiële correlaties, latente-variabelemodellen, en mediatie-analyse.

Nadat we een wiskundig model voor onze data hebben gekozen, moeten we de modelparameters schatten en nagaan of het gekozen model inderdaad een adequate beschrijving van de data biedt. Hoe kunnen we het beste psychologische datasets die beschreven zijn met behulp van mathematische modellen analyseren? In dit proefschrift stelde ik dat dit het beste gedaan kan worden door middel van Bayesiaanse inferentie. Ik heb beweerd dat Bayesiaanse statistiek belangrijke theoretische en praktische voordelen biedt ten opzichte van frequentistische statistiek, voordelen die Bayesiaanse procedures bij uitstek geschikt maken om de problemen uit de dagelijkse werkpraktijk van psychologisch onderzoek aan te pakken.

In rest van deze samenvatting zal ik een overzicht en een korte beschrijving geven van de vraagstukken waarmee ik me tijdens mijn promotieproject heb beziggehouden. In dit proefschrift zijn zeer verschillende onderwerpen verkend; de gemene deler is de toewijding aan mathematisch modelleren en zorgvuldige statistische inferentie.

Deel I. De Analyse van Responstijdverdelingen

Het eerste deel van dit proefschrift richtte zich op het modelleren van responstijden—zowel geobserveerde als niet geobserveerde—met behulp van de ex-Gaussian en shifted Wald-responstijdverdelingen.

In het tweede hoofdstuk onderzocht ik de validiteit van de cognitieve interpretatie van de parameters van de ex-Gaussian en shifted Wald verdelingen. De ex-Gaussian en de shifted Wald zijn veelgebruikte statistische modellen voor het beschrijven van responstijdverdelingen in snelle tweekeuzetaken, waarvan de parameters vaak geïnterpreteerd worden in termen van cognitieve processen. We hebben de validiteit van deze cognitieve interpretatie onderzocht door de parameters van de ex-Gaussian en shifted Wald-verdelingen te relateren aan de parameters van het Ratcliffdiffusiemodel (Ratcliff, 1978), een succesvol procesmodel waarvan de parameters een gegronde cognitieve interpretatie kennen (e.g.,Voss et al., 2004). De resultaten tonen aan dat de ex-Gaussian en shifted Wald-parameters niet uniek overeenkomen met de parameters van het diffussiemodel. De cognitieve interpretatie van de parameters van deze verdelingen wordt daarom afgeraden.

In het derde hoofdstuk introduceerde ik een Bayesiaanse parametrische methode voor het schatten van de tijd die mensen nodig hebben om hun respons af te breken (stopsignaalresponstijd; SSRT) in het stopsignaalparadigma. Het stopsignaalparadigma is een populair experimentele procedure die wordt gebruikt om het onderdrukken van responsen op tweekeuzetaken te onderzoeken. Gebaseerd op het racemodel (Logan & Cowan, 1984) zijn verscheidende methoden ontwikkeld om SSRT's te schatten die anders niet geobserveerd zouden kunnen worden. Geen van deze methoden is echter in staat om een accurate schatting te maken van de gehele verdeling van SSRT's, terwijl responstijdverdelingen juist waardevolle informatie kunnen bevatten voor de onderzoeker (Heathcote et al., 1991). We introduceerden een Bayesiaanse methode om deze beperking te verhelpen. Deze nieuwe aanpak doet de aanname dat SSRT's een ex-Gaussian-verdeling volgen en gebruikt Markov chain Monte Carlo (Gamerman & Lopes, 2006; Gilks et al., 1996) sampling om de posterior-verdeling van de parameters te schatten. We toonden aan dat de Bayesiaanse methode in staat is de ware waarden van de parameters terug te schatten in datasets van een realistische omvang. We raadden onderzoekers aan de voorgestelde methode consequent te gebruiken en de hele verdeling van SSRT's te beschouwen bij het analyseren van stopsignaaldata.

In het vierde hoofdstuk presenteerde ik BEESTS, een efficiënte en gebruiksvriendelijke software-implementatie van de Bayesiaanse parametrische methode die geïntroduceerd werd in hoofdstuk 3. BEEST heeft een eenvoudig te gebruiken grafische gebruikersinterface en voorziet gebruikers van kengetallen van de posterior-verdeling van de parameters, alsook verschillende diagnostische middelen om de kwaliteit van de parameterschattingen te beoordelen. We illustreerden het gebruik van BEESTS aan de hand van gepubliceerde stopsignaaldata. Deze software maakt het schatten van SSRT verdelingen ook toegankelijk voor de toegepaste wetenschap.

Deel II. Multinomiale *Processing-Tree*-Modellen

Het tweede deel van dit proefschrift richtte zich op modelselectie en het schatten van parameters voor multinomiale *processing-tree* (MPT) modellen. MPT-modellen zijn theoretisch gemotiveerde stochastische modellen voor categorische data. Als gevolg van hun eenvoud worden MPT-modellen frequent en in veel verschillende gebieden toegepast binnen de cognitieve psychologie (e.g., Batchelder & Riefer, 1999).

In het vijfde hoofdstuk introduceerde ik een Bayesiaanse aanpak voor het schatten van parameters van MPT-modellen. MPT-modellen worden gewoonlijk toegepast op geaggregeerde data, waarbij de onrealistische aanname wordt gedaan dat er geen heterogeniteit bestaat tussen de parameters (Hu & Batchelder, 1994). Onze voorgestelde Bayesiaanse aanpak houdt rekening met de heterogeniteit van de model parameters, die kan ontstaan als gevolg van individuele verschillen zowel tussen proefpersonen als items. We hebben het gebruik van de nieuwe methode geïllustreerd aan de hand van experimentele data verkregen uit de *pair-clustering*-taak (Batchelder & Riefer, 1980), een geheugentaak waarin proefpersonen semantisch gerelateerde woorden moeten onthouden. We raadden onderzoekers aan om de voorgestelde methode consequent toe te passen om de vertekening van parametersschattingen als gevolg van parameterheterogeniteit te voorkomen.

In het zesde hoofdstuk presenteerde ik verschillende procedures voor modelselectie voor MPT-modellen. Het onderwerp van kwantitatieve modelselectie krijgt van oudsher veel aandacht in de statistiek en tegenwoordig ook in de psychologie (Pitt & Myung, 2002). We richtten ons op twee populaire informatiecriteria, namelijk de AIC ("an information criterion", Akaike, 1973) en de BIC ("Bayesian information criterion", G. Schwarz, 1978), het *minimum-description-length*-principe (Grünwald, 2007), en de Bayes-factor verkregen met importance sampling (Hammersley & Handscomb, 1964). Naast de beschrijving van deze methode werd computercode geleverd die de praktische toepasbaarheid van de besproken modelselectiematen verhoogt.

Deel III. Correlaties, Partiële Correlaties en Mediatie-analyse

Het derde deel van dit proefschrift behandelde het schatten en toetsen van (partiële) correlaties.

In het zevende hoofdstuk onderzocht ik het onderscheidingsvermogen om de hypothese van perfecte correlatie te verwerpen binnen latente-variabelemodellen. In onderzoek waarbinnen hiarchische latente-variabelenmodellen worden gebruikt, wordt vaak gerapporteerd dat algemene intelligentie (g) een perfecte correlatie vertoont met lagere orde latente variabelen. Hieruit wordt vaak geconcludeerd dat g en de lagere orde latente variabele, zoals werkgeheugen, één en hetzelfde zijn. We hebben op basis van simulaties en gepubliceerde datasets onderzocht wat het onderscheidingsvermogen is om de gelijkheid van g en de lagere orde latente variabelen te verwerpen. De resultaten toonden aan dat het overgrote deel van de studies die een perfecte correlatie rapporteerden over onvoldoende onderscheidsvermogen beschikten om aan te tonen dat g en de lagere orde latente variabelen identiek zijn. We benadrukten het belang van het onderscheidingsvermogen in onderzoek naar de equivalentie van g en lagere orde latente variabelen.

In het achtste hoofdstuk behandelde ik een Bayesiaanse methode om de correlatiecoëfficiënt te corrigeren voor de onzekerheid van de observaties. De correlatiecoëfficiënt kan ernstig worden onderschat wanneer de observaties onderhevig zijn aan meetfouten. Hoewel verschillende methoden ontwikkeld zijn om hiervoor te corrigeren, worden deze amper toegepast in de psychologie. We richtten ons op een Bayesiaanse correctiemethode, ontwikkeld door Behseta et al. (2009), en toonden aan dat het toepassen hiervan tot een substantiële verhoging van de correlatie kan leiden tussen met ruis gemeten observaties. We raadden onderzoekers aan zich bewust te zijn van meetfouten en, indien mogelijk, de correlatiecoëfficiënt corrigeren voor de attenuatie die op kan treden als gevolg van de onzekerheid van de observaties.

In het negende hoofdstuk besprak ik een Bayesiaanse hypothesetoets voor mediatie. Om de relatie tussen verschillende variabelen te kunnen kwantificeren, voeren onderzoekers vaak een mediatie-analyse uit. In een dergelijke analyse verstuurt een mediator (zoals kennis van een gezond dieet) het effect van een onafhankelijke variabele (zoals instructie over een gezond dieet) naar een afhankelijke variabele (zoals de consumptie van fruit en groente). Vrijwel alle mediatie-analyses in de psychologie gebruiken frequentistische parameterschattingen en hypothesetoetsing. We ontwikkelden echter een Bayesiaanse hypothesetoets die gebaseerd is op de Jeffreys-Zellner-Siow prior (Rouder et al., 2009) en hebben de voordelen daarvan geïllustreerd aan de hand van gepubliceerde data.

Deel IV. Verbeteren van de Onderzoekspraktijk

Het vierde en laatste deel van dit proefschrift richtte zich op suboptimale onderzoekspraktijken binnen de psychologie.

In het tiende hoofdstuk introduceerde ik een nieuwe opzet voor samenwerking tussen voor- en tegenstanders van een empirische bevinding (*adversarial collaboration*). Een toenemend aantal wetenschappers suggereert dat horizontale saccadische oogbewegingen het ophalen van episodische herinneringen in geheugentaken faciliteren. Een aantal studies heeft dit verband echter niet weten te reproduceren. We hebben gepoogd deze inconsistente bevindingen op te lossen door een gezamenlijk onderzoek uit te voeren met voorstanders en sceptici. Onze aanpak combineerde elementen van een *adversarial collaboration* (Kahneman, 2003) en volledig confirmatorisch gepreregistreerd onderzoek (Wagenmakers et al., 2012). Conform de verwachtingen van de sceptici toonden de resultaten van Bayesiaanse hypothesetoetsen aan dat horizontale oogbewegingen de prestaties in geheugentaken niet verbeterden. Het toepassen van deze opzet vermindert de kans op het gebruik van *questionable research practices* en heeft de potentie om wetenschappelijk onenigheden op te lossen.

In het elfde hoofdstuk presenteerde ik een vergelijking tussen het statistisch bewijs dat wordt geleverd door p-waarden, effectgroottes en Bayes-factoren. Hierbij maakten we gebruik van 855 recent gepubliceerde t-toetsen in de psychologie. Hoewel de p-waarde en de Bayes-factor vrijwel altijd dezelfde hypothese ondersteunden, was er vaak sprake van verschil tussen de kracht van het geleverde bewijs; 70% van de p-waarden tussen 0.01 en 0.05 correspondeerden met Bayes-factoren die slechts anekdotisch bewijs leverden voor de alternatieve hypothese. Daarnaast concludeerden we dat de effectgrootte aanvullend bewijs kan leveren aan de p-waarde en de Bayes-factor.

In het twaalfde en laatste hoofdstuk, behandelde ik de meerweg-variantieanalyse (ANOVA). Veel onderzoekers realiseren zich niet dat de veelgebruikte meerweg-ANOVA onderhevig is aan kanskapitalisatie. We hebben het gebruik van sequentiele Bonferroni-correctie (Hartley, 1955) geïllustreerd. We lieten zien dat de conclusies die uit een ANOVA-design worden getrokken, vaak veranderen na toepassing van deze correctie en raadden de consequente toepassing ervan aan.

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