King Saud University

College of Engineering

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Chapter 3. Information Input and Processing

Part – 4: Signal Detection Theory

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Contents

- A Model of Information Processing
- Perception
- Signal Detection Theory

A Model of Information Processing

A Model of Information Processing

- What are models? What are they used for?
  - Models are "abstract representations of a system or process"
  - Best way to evaluate models is to see what they are used for
  - "Good" model = one that can represent behavior of actual system well

- Types of models:
  - Mathematical, physical, structural, verbal
  - Information theory: mathematical model of info. transfer in communication systems
  - Signal Detection Theory: also mathematical model

- Stages of Human Information Processing:
  - Model of human information processing (*next slide*) shows
    - Major stages of human info. Processing
    - Relationships between them

Cont. A Model of Information Processing

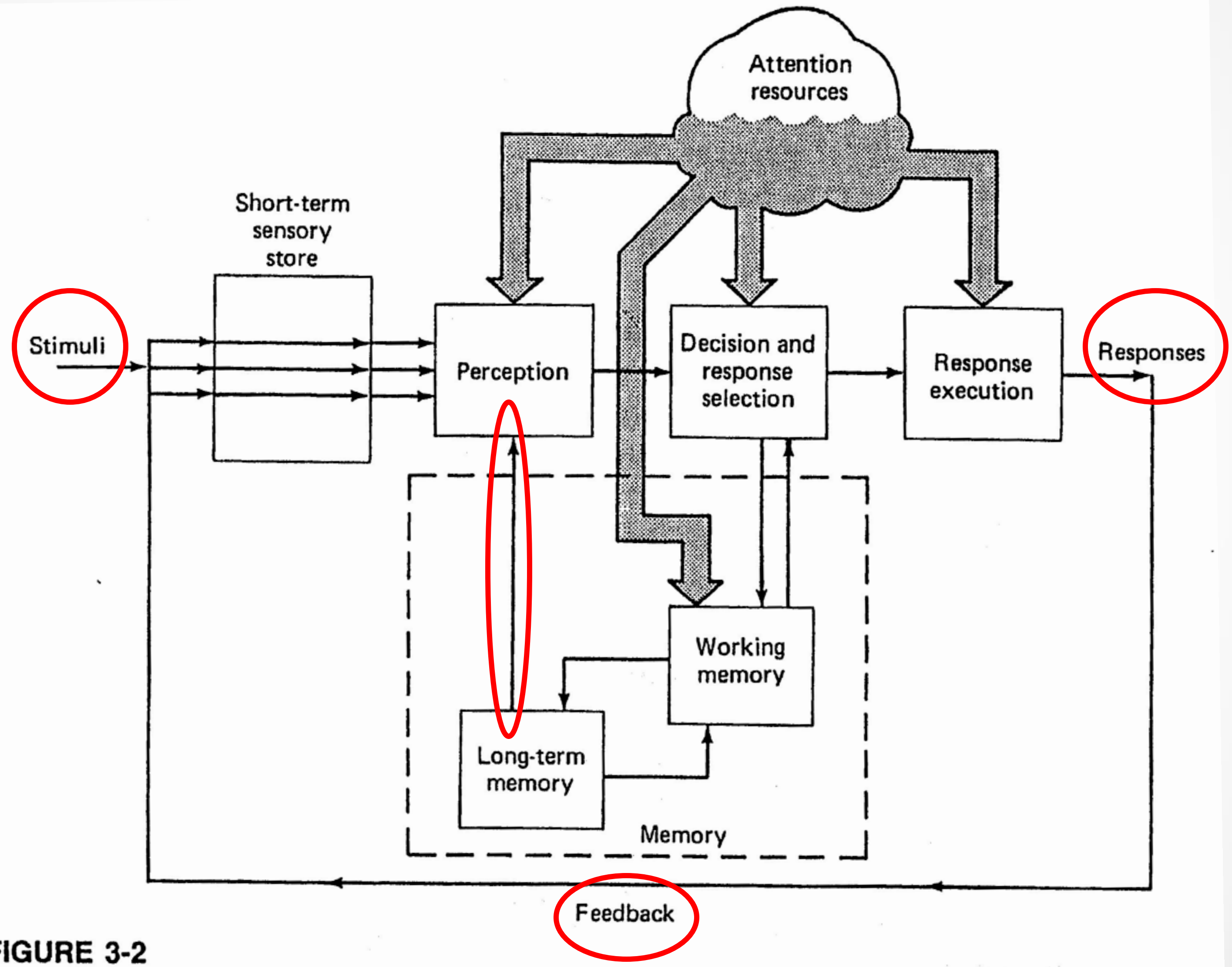


FIGURE 3-2
A model of human information processing showing the major processes, or stages, and the interrelationships. (*Source: Wickens, 1984, Fig. 1.1. Reprinted by permission of the publisher.*)

Perception

Perception

- Levels of Perception
  - Level of perception depends on: stimulus & task that person faces
  - Forms of perception:
    - Detection (most basic form): determine if signal is present/not
    - Identification/Recognition: indicating in which class target belongs
    - Multilevel classification: making abs. judgment along stimulus dimension

- Activities Involved with Perception:
  - Perception involves our prior
    - Experiences
    - Learned associations (line connecting long-term memory – perception)
  - Simple detection involves complex
    - Information processing
    - Decision making
  - This is included within signal detection theory

Signal Detection Theory

Signal Detection Theory

- Overview of Signal Detection Theory (SDT)
  - Involves situations where
    - Two discrete situations exist: signal / no signal
    - Situations cannot be easily discriminated
  - Examples:
    - Detecting cavity on tooth x-ray
    - Detecting defective component in a factory
    - Detecting rain in weather forecast

- Concepts Associated with SDT
  1. Concept of noise
  2. Possible outcomes
  3. Concept of response criterion
  4. Influencing the response criterion
  5. Concept of sensitivity
  6. Applications of SDT

Cont. Signal Detection Theory

1. Concept of Noise

- Nature of Noise:
  - Involved with any situation
  - Interferes with detection of signal

- Noise is generated:
  - Externally (e.g. false radar return on radar screen)
  - Internally: within person (e.g. miscellaneous neural activity)

- Noise value:
  - Intensity varies from low to high with time
  - Forms normal (bell-shaped) distribution

- When “signal” occurs:
  - Intensity is added to background noise
  - Person must decide if input (what s/he senses) consists of:
    - Only noise, or
    - Noise + signal

Cont. Signal Detection Theory

2. Possible Outcomes

- First note the following:
  - Person must decide: signal occurred / did not occur (2 possibilities)
  - There are two realities: signal did occur / did not occur

- Thus, there are four possible outcomes:
  - *Hit*:
    saying "signal" where there is signal
  - *False Alarm* (FA):
    saying "signal"/there's no signal
  - *Miss*:
    saying "no signal" / there is signal
  - *Correct Rejection (CR)*:
    saying "no signal" / there's no signal

Response	Signal	
	Yes	No
Yes	s / y	s / n
No	ns / y	ns / n

⇓

Response	Signal	
	Yes	No
Yes	*HIT*	*FA*
No	*MISS*	*CR*

Cont. Signal Detection Theory

3. Concept of Response Criterion

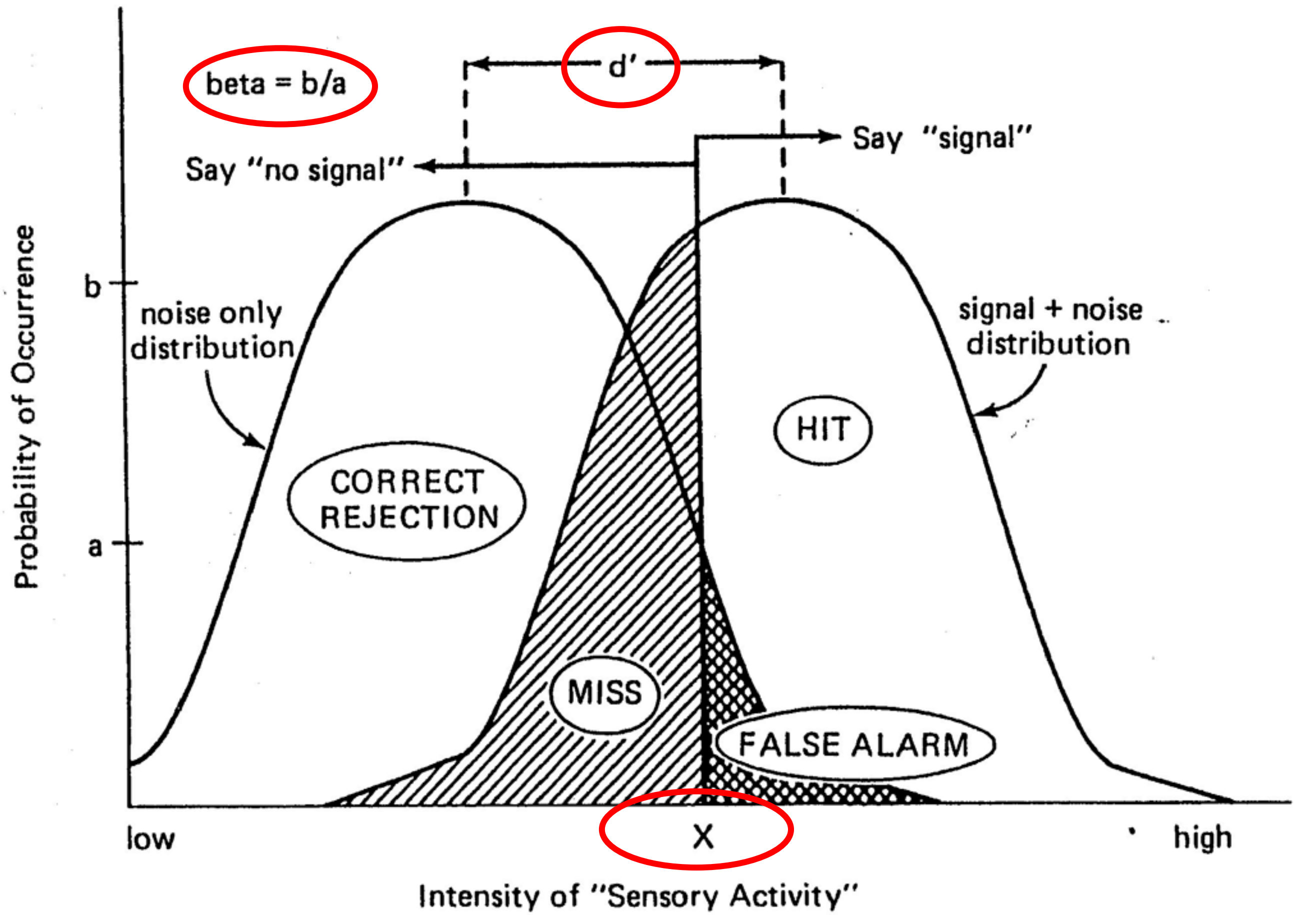
- SDT helps with understanding how detection process works

- Basis of SDT:
  - People set criterion along "hypothetical continuum of sensory activity"*
  - People then use this as a basis for making their decisions
  - We then find out position of criterion along continuum
  - This determines probability of four outcomes (*last slide*)
  - This process is illustrated in next slide (Figure 3-3)

- Notes regarding Figure 3-3:
  - Figure shows hypothetical distributions of sensory activity in cases:
    - Only noise is present
    - Signal is added to noise
  - The two distributions (noise and signal + noise overlap)
    - $\Rightarrow$ noise level alone may be > signal + noise (in which case?)

Cont. Signal Detection Theory

FIGURE 3-3
Illustration of the key concepts of signal detection theory. Shown are two hypothetical distributions of internal sensory activity, one generated by noise alone and the other generated by signal plus noise. The probabilities of four possible outcomes are depicted as the respective areas under the curves based on the setting of a criterion at X. Here *d′* is a measure of sensitivity, and beta is a measure of response bias. The letters *a* and *b* correspond to the height of the signal-plus-noise and noise-only distributions at the criterion.



Cont. Signal Detection Theory

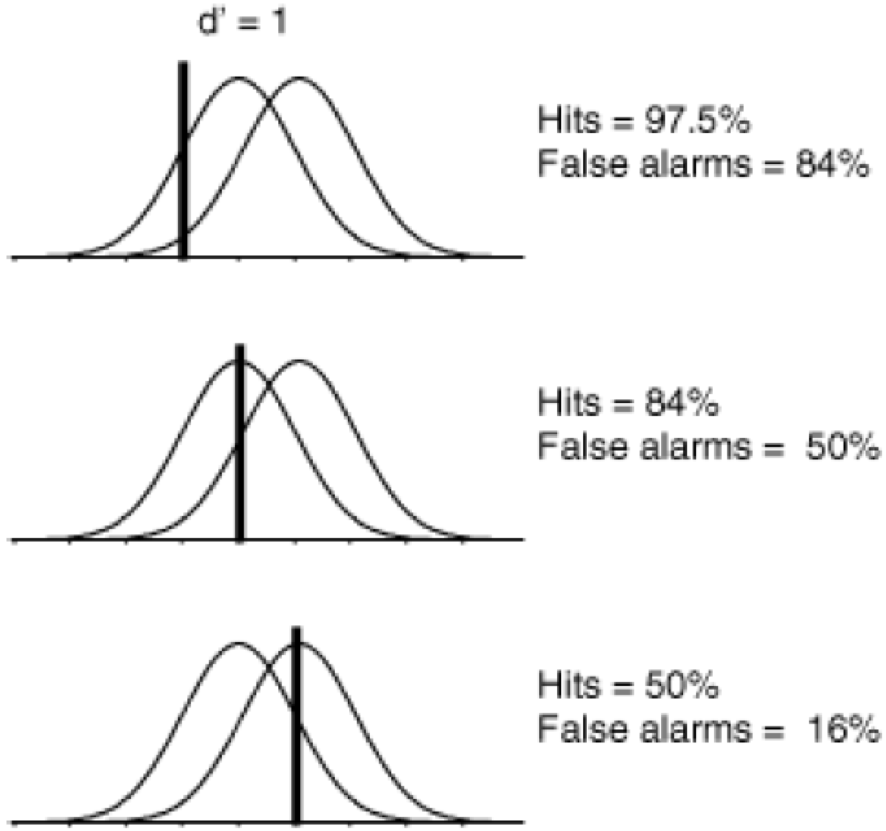
3. Cont. Concept of Response Criterion (RC)

- SDT assumes person sets criterion, such that when:
  - Level of sensory activity > set criterion ⇒ person says: "signal present"
  - Level of sensory activity < set criterion ⇒ person says: "no signal"
  - Probabilities of four outcomes determined based on criterion (Figure)

- Quantity "beta" (aka response criterion / response bias)
  - Based on position of criterion
  - $beta = b / a$
  - i.e. beta is ratio of signal : noise, or ratio of height of 2 curves @ criterion
  - Values of beta (*see next slide*)
    - Beta = 1, when two distributions intersect (can you show this?)
    - When criterion is shifted to right ⇒
      - Beta increases (i.e. > 1.0)
      - Person says "signal" less ⇒ hits ↓, but also FA ↓
      - Person is considered: "conservative"
    - When criterion is shifted to left ⇒
      - Beta decreases (i.e. < 1.0)
      - Person says "signal" more ⇒ hits ↑, but also FA ↑
      - Person is considered: "risky" (aka "liberal")*

Cont. Signal Detection Theory

Effect of changing $beta$ / criterion (constant d')



Cont. Signal Detection Theory

4. Influencing the Response Criterion

- Two variables affect setting the criterion
  1. Probability of detecting a signal
  2. Costs and benefits associated with 4 possible outcomes

1. Probability of detecting a signal:
   - e.g. If you told dentist tooth was hurting you ⇒
   - Probability that you have cavity ↑
   - ⇒ after seeing suspicious spot on x-ray ⇒ dentist will likely say: "cavity"
   - ⇒ criterion ↓ (i.e. beta ↓) ⇒ i.e. dentist can make "risky" assessment

2. Costs and benefits associated with 4 possible outcomes
   - What is cost of *false alarm* (saying "cavity", when there's no cavity)?
     - ⇒ tooth gets drilled without need
   - What is cost of *miss* (saying "no cavity", when there is cavity)?
     - ⇒ cavity worsens ⇒ may lose tooth
   - So, what should dentist do? (i.e. after weighing costs?)
     - Most likely: set low criterion ⇒ call suspicious spot: "cavity"
     - But what if you go regularly? ⇒ he will be more conservative (why?)* ⇒ will set a high criterion, and will not call it "cavity"

Cont. Signal Detection Theory

5. Concept of Sensitivity

- o What is sensitivity? It is keenness / resolution of sensory system
- o RC vs. sensitivity in SDT: they are both independent of each other

- o How to measure sensitivity (aka: d')
  - Sensitivity: d' = separation between 2 distributions (*see Figure 3-3*)
  - Measured in units of standard deviation: (aka *Z-score*)
  - SD's of 2 distributions are assumed equal
  - As separation ↑ ⇒ sensitivity ↑ ⇒ d' ↑ (note, best to have high d' *)
  - Most applications: $d' = [0.5 - 2]$ (*see next slide*)

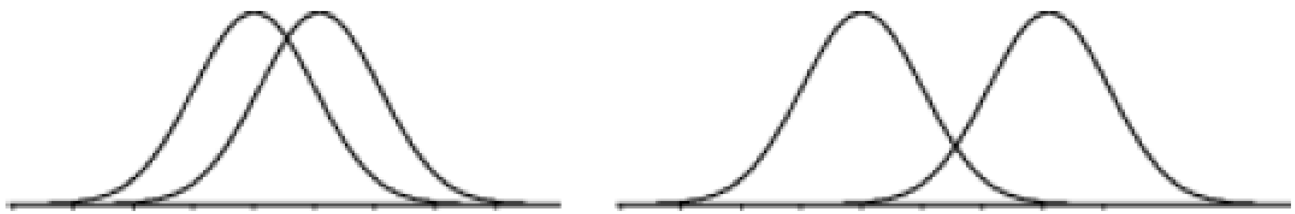
- o Factors affecting d'
  1. Some signal systems have more noise than others, thus:
     - o As noise ↑ ⇒ d' ↓
     - o Also note, as signal ↓ ⇒ d' (*can you show this on Figure 3-3?*)
  2. Ability of people to memorize physical characteristics of signal
     - o Memory aids ⇒ d' ↑ (*see Figure 3-2*)
     - o e.g. for dentist: d' ↑ by:
       - Using better x-ray equipment
       - Comparing x-ray of patient with previous x-rays of cavities

Cont. Signal Detection Theory

Receiver Operating Characteristic

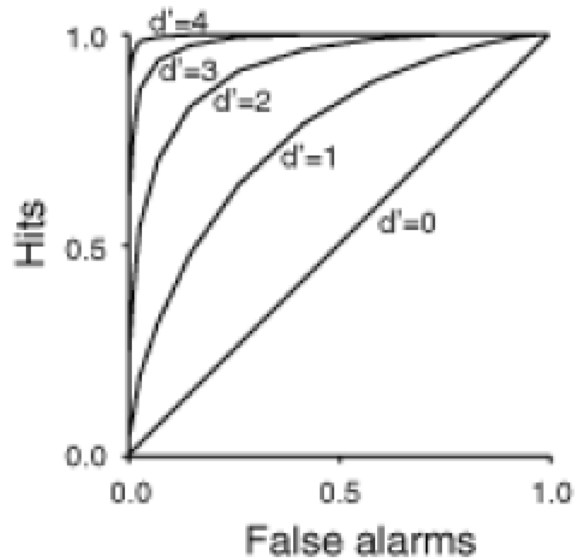
- ROC curves

Effect of changing *d'*



d' = 1 (lots of overlap)

d' = 3 (not much overlap)

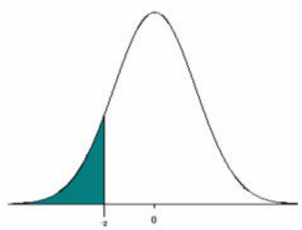


ROC curves

Cont. Signal Detection Theory

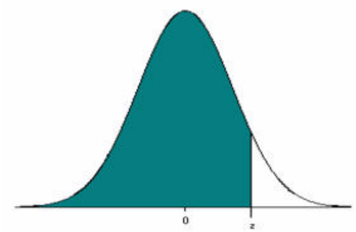
6. Applications of SDT
   - o Many practical applications (from various studies):
     - Sonar target applications
     - Industrial inspection tasks
     - Medical Diagnosis
     - Forensic science
     - Eye witness testimony
     - Air traffic control
     - Weather forecasting
   - o Reservations
     - SDT should not be accepted without criticism (use with “grain of salt”)
       - o Using in some situations may ⇒ invalid results
     - Reasons:
       - o Theory developed in lab (controlled conditions/experiments)
       - o Subjects given many, many trials
       - o Controlled signals and background noise levels
       - o Some applications don’t match these conditions

Table of Standard Normal Probabilities for Negative Z-scores



z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
-3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
-3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
-3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
-3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
-2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
-2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
-2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
-2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
-2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
-2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
-2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
-1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
-1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
-1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
-1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
-1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
-1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
-1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
-1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
-0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
-0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
-0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
-0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
-0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
-0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
-0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641

Table of Standard Normal Probabilities for Positive Z-scores



z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Note that the probabilities given in this table represent the area to the LEFT of the z-score.
The area to the RIGHT of a z-score = 1 – the area to the LEFT of the z-score